Science Indicators 1982

An Analysis of the State of U.S. Science, Engineering, and Technology

National Science Board

1983

NATIONAL SCIENCE BOARD

Science Indicators 1982

Report of the National Science Board 1983

National Science Board
National Science Foundation

Letter of Transmittal

November 21, 1983

My Dear Mr. President:

I have the honor of transmitting to you, and through you to the Congress, *Science Indicators—1982,* the sixth in a series of the Board's biennial reports devoted to a quantitative assessment of the status of science and technology in the United States. This document is being submitted as the initial response to the 1982 amendment of the National Science Foundation Act which requires for the first time that the Board prepare such a report.

The expansion of national support for research and development by both Government and industry in recent years demonstrates that science and technology continue to receive priority for investment, reflecting their importance to the economy and to national security. Through the *Science Indicators* series, the Board strives to contribute to a better understanding of the science and technology enterprise and to the formulation of related policies.

This publication analyzes science and technology activities in the United States and their relationship to the efforts of other major industrialized countries. It provides for the first time a separate treatment of academic science and engineering. The report also presents information on public attitudes toward science and technology and recent accomplishments in research and development.

I hope that this report will be of special interest to you and will stimulate discussion and analysis in the science and technology policy community.

Respectfully yours,

Lewis M. Branscomb
Chairman, National Science Board

The Honorable
The President of the United States
The White House
Washington, D.C. 20500

Contents

Introduction

With the release of *Science Indicators—1972,* the National Science Board initiated a series of biennial reports on the state of the U.S. scientific endeavor. The present report, the sixth in the series, continues the presentation of quantitative indicators of the many facets of organized science and technology, accompanied by trend analyses and interpretation.

These quantitative measures aim to provide a broad base of information to assist the planning, debate, and negotiation which surround the specific issues faced by policymakers. They are not intended to replace the judgment of such decisionmakers, but to inform them. As individual measures, these indicators cannot capture the fullness of the scientific enterprise; taken together, they reflect the variety and character of U.S. science and engineering. When considered as multiple indicators of a phenomenon, these data and analyses present a more comprehensive picture and encourage broader perspectives. As is true of all indicators, they illuminate by providing *indirect* reflections of status, behavior, or performance.

A comprehensive appraisal of the American science and technology system must include many areas: the inputs to the system in terms of funds, personnel, and institutions; the varying approaches taken in pursuit of different research goals; the sophisticated equipment and instrumentation by which our powers of observation are greatly expanded and our scientific results put to use; the various forms of documenting and disseminating research results; the impact of research and development investment on the Nation's general economic and social well-being; and many others. A complete assessment of such characteristics requires examining the system both from internal and external vantage points.

Such an effort involves many approaches, diverse data sources, and a wide range of analytical and statistical methods. Thus, the creation of sophisticated methodologies for such an appraisal in itself raises major research questions. The complexity of the U.S. infrastructure for science, engineering, and technology makes the challenge of understanding its dynamics even more demanding. The diverse settings for the performance of R&D, the multiple sources of its support, its relation to scientific and technological developments across the world, the dispersed loci of policymaking in science and engineering, and the multiplicity of purposes served—all illustrate the importance of a multidimensional approach to the understanding of the U.S. science and technology enterprise.

Because the substantive aspects of science and technology are not easily captured by quantitative indicators, this report contains a chapter entitled "Advances in Science and Engineering." This chapter attempts to convey the process and significance of research by describing a few illustrative areas: prime numbers, the pursuit of fundamentality and unity, the science of surfaces, man-made baskets for artificial enzymes, opiate peptides and receptors, plant disease, cognitive development in early childhood, and exploration of the ocean floor. These eight topics are not intended to be fully representative of the wide scope of modern research activity, nor are they necessarily the most important areas being investigated; instead, they exemplify recent trends in the cumulative development of a few sample areas.

Science Indicators—1982 presents one major innovation in the organization of the publication. In past reports, material on academic science and engineering was covered in a dispersed fashion in various chapters. With the present report, the National Science Board is introducing a separate chapter that covers in an integrated fashion indicators of academic science and engineering. Since it is in the Nation's universities and colleges that future scientists and engineers are trained and a large proportion of the more fundamental research is performed, it is important that S&T policymakers have a clear picture of the status and recent trends in the academic sector.

The reports in the *Science Indicators* series have changed gradually, as the information needs of their audience have become clearer and as new data, methodologies, and analyses have been developed. Progress in this evolution results from the contributions of those individuals who bring their expertise and innovative ideas to fruition within the purposes and scope of the *Science Indicators* concept. Numerous reviews and the feedback from users of these reports continue to illustrate the need for better indicators, and specific suggestions are welcomed. In this regard, the National Science Foundation supports research to stimulate developments in this area, with the expectation of improving future *Science Indicators* volumes.

As can be seen from the following acknowledgments and Appendix II, many individuals aided in the preparation of this report. The overall responsibility was that of the National Science Board, assisted by a special committee of its members. The preparation of the report was assigned to the Directorate for Scientific, Technological, and International Affairs (STIA) and the manuscript was prepared by the Division of Science Resources Studies.

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Acknowledgments

The National Science Board extends its appreciation to the following members of the National Science Foundation who provided primary assistance with the preparation of this report:

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The Board is also grateful to the special contributors and to those who reviewed the various chapters of *Science Indicators—1982*, all of whom are listed in Appendix II.

[1] Through May 8, 1982
[2] Through January 12, 1983

Chapter 1
International Science and Technology

International Science and Technology

HIGHLIGHTS

- The indicators presented in this chapter demonstrate that the United States still maintains an overall S/T leadership position in terms of its absolute investments in R&D, contribution to scientific and technical literature, positive balance in R&D-intensive trade, and the sale of technical knowledge. On the other hand, U.S. inventive activity appears to have decreased relative to some foreign competitors, and the U.S. share of world exports in R&D-intensive products has declined. During the early 1970's, other nations, particularly Japan and West Germany, increased their S/T investments and activities relative to the United States and thereby narrowed the gap. However since the mid-1970's, the United States has kept pace with the R&D investment trends of other industrialized nations.
- In 1979 the United States spent about as much on research and development (R&D) as France, West Germany, Japan, and the United Kingdom combined. Ten years earlier, U.S. research and development expenditures were more than twice as much as the combined R&D expenditures of these countries. Among these countries the United States accounted for about 70 percent of combined R&D expenditures in 1969 and about 50 percent in 1979. (See p. 3.)
- The United States devotes a higher proportion of its gross national product (GNP) to research and development than almost any other country. The U.S. ratio was as high as 3.0 percent in 1964. After a decline, the ratio began rising again in the late 1970's and is estimated to be about 2.7 percent in 1983. Japan and West Germany have increased their R&D/GNP spending ratios throughout this period. Since the mid-1970's, West Germany's ratio has been about the same as that of the United States, while Japan's ratio in 1981 was 2.4 percent. (See pp. 6-7.)
- West Germany and Japan have the highest percentages of GNP devoted to national civilian R&D expenditure and have continued to increase their investments in these areas. West Germany's ratio reached 2.5 percent and Japan's was 2.3 percent in 1981, compared with 1.7 percent for the United States. Although the U.S. civilian R&D-to-GNP ratio is lower, it has risen since the mid-1970's, and is estimated to have reached about 1.8 percent in 1983. (See pp. 7-8.)
- The number of scientists and engineers (S/E's) engaged in R&D is higher in the United States than in almost any other country—about 720,000 in 1982. The Soviet Union is the only country with a larger R&D work force. Even when related to the size of its total labor force, the United States has the highest proportion of R&D scientists and engineers (63.8 per 10,000 persons in the labor force) of any country except the Soviet Union. Since the mid-1970's the U.S. ratio has been rising, as have the Japanese and West German ratios. (See pp. 4-5.)
- Investments in R&D and technological innovation have positive long-term effects on productivity and economic growth. The United States maintains the highest overall productivity level, but has experienced slower growth rates in manufacturing productivity than have most industrialized countries. From 1975 to 1982, productivity in manufacturing industries in the United States increased 11 percent. Productivity rose more than four times faster in Japan, more than three times faster in France, and over twice as fast in West Germany and the United Kingdom. (See pp. 17-18.)
- New capital investments often embody new technologies and/or R&D advances, and replacement of capital equipment is an important factor in productivity growth. Over the past decade, capital investment as a percent of output has been smaller in the United States than in other major industrialized countries. In 1980-1981, Japan had a capital investment rate almost twice that of the United States. (See pp. 18-19.)
- Scientific and technical publication counts serve as an output indicator of S/E research activity. In 1980, U.S. scientists and engineers contributed a high overall share (37 percent) of the world's articles in over 2100 highly cited influential scientific and technical journals. However, biomedicine is the only field that actually increased from 1973 to 1980 in terms of the number of U.S. articles; most of the other fields actually experienced declines, whereas the number of non-U.S. articles rose in all but two fields. U.S. scientific literature is widely respected; U.S. articles published in 1978 have since been cited 45 percent more than could be explained solely by the number of articles produced. From 1973 to 1978, foreign use of U.S. literature increased in the fields of chemistry, mathematics, and earth and space sciences, but decreased in the fields of biomedicine, biology, physics, and engineering and technology. (See pp. 11-12.)
- Patent data can be used as an indicator of inventive activity. Between 1971 and 1982, U.S. domestic patenting dropped almost 40 percent, and U.S. patenting abroad also declined substantially. Foreign patenting in the United States increased between 1971 and 1974, remained relatively level afterwards, and in 1982 constituted over 40 percent of all U.S. patents granted. Most of the increase in foreign patenting was due to Japanese inventors.

Domestic patenting in Japan increased over 70 percent between 1971 and 1977 and has leveled off since. The number of Japanese-origin patents granted by the United States has increased steadily and has more than doubled since 1971. (See pp. 12-15.)

- Highly cited patents can be used as an indicator of significant inventions. U.S. inventors have a larger percentage of highly cited U.S. patents than foreign inventors (and therefore a technical advantage) in the product fields of ordnance except missiles, food and kindred products, and primary metals, chemicals and allied products, and electrical and electronic equipment. However, a greater percentage of U.S. foreign-origin patents are highly cited than are U.S. domestic patents in a number of other product fields, including engines and turbines, aircraft and parts, professional and scientific instruments, motor vehicles, and other transportation equipment. (See pp. 14-15.)
- The U.S. trade balance in R&D-intensive manufactured products has been positive and growing over the past decade, reaching a surplus of $52.4 billion in 1980. Thus the United States has a competitive advantage in these products. There have been some changes in this position. The trade balance with Japan has declined since the mid-1970's and registered -$3.6 billion in 1980. The U.S. share of world exports of R&D-intensive manufactured products was 23 percent in 1970 and 20 percent in 1980. Over the same period, the Japanese share increased from 10 percent to almost 15 percent. U.S. worldwide market shares have declined in aircraft, electronic components, and jet engines, but have increased in computers. (See pp. 20-23.)
- Data on international transactions in royalties and fees are frequently used as indicators of technology transfer and show that, in dollar terms, in 1981 the United States sold about nine times more technical know-how through these channels than it bought; U.S. receipts for royalties and fees rose more than 70 percent since the mid-1970's and in 1981 totaled $6.9 billion. The United States is a net exporter of technology, while Japan, West Germany, and France are all net importers of technical know-how. About 80 percent of these transactions are with U.S. subsidiaries abroad. This affords greater control by U.S. firms over the use of their technology. There is likely to be less control over technology transferred to unaffiliated firms. In 1971, over 70 percent of the U.S. transactions with Japan were with unaffiliated firms; but by 1981, U.S. receipts of royalties and fees were about equally divided between unaffiliated Japanese companies and U.S. subsidiaries in Japan. (See pp. 23-25.)
- Publications produced jointly by scientists and engineers of different countries constitute one measure of international scientific cooperation. Such joint-authorship has increased slightly in all fields combined—from 13 percent of all multiple-authored publications in 1973 to 16 percent in 1980. By this measure, the most internationally cooperative fields worldwide are mathematics, the earth and space sciences, and physics. The United States and Japan have the lowest ratios of international cooperative authorship of the major industrialized countries; in 1980 their ratios were less than half those of West Germany, the United Kingdom, and Canada. (See pp. 29-31.)
- U.S. universities and colleges have long been involved in a variety of international science and technology activities, their main contribution being the education of foreign students. About 22 percent of the S/E doctorates granted by U.S. universities were awarded to foreign citizens in 1981. In engineering alone, foreign citizens constituted more than one-half of the graduating doctorates. (See pp. 28-29.)

Science and technology (S/T) transcend national borders, both in terms of content and economic, societal, and cultural impacts. The current S/T knowledge base has been developed by scientists and engineers from many nations. In light of the global nature of science and technology, this chapter examines U.S. scientific and technical capabilities and activities in an international context, by presenting international comparisons of science and technology resources, outputs, impacts, and collaboration.

The first section presents international comparisons of investments in research and development and includes various indicators concerning S/T personnel and the amount of expenditures devoted to R&D. Absolute levels of these investments are discussed because the quantity of resources available often influences the breadth and scope of S/T activities a country can support. However, in order to make more meaningful comparisons between countries, indicators that normalize for the size of a nation's economy or labor force are also found here.

Although it is difficult to quantify precisely all the results of R&D investments, the second section of this chapter discusses some of the outputs of research and development. Because the publication of scientific and technical literature is one of the more direct outputs of research, the U.S. contribution to, and impact on, world science is examined in terms of the number and relative citation ratios of S/T articles published by U.S. scientists and engineers. Although there are important limitations, patent data can be used as output indicators of technological invention as well as commercial interest in foreign markets. This section also presents measures of U.S. and foreign patenting activity.

S/T activities have important long-term results, particularly economic impacts. Unless R&D results are utilized, they cannot effectively influence economic growth. The third section of this chapter thus deals with productivity and technological advances and compares productivity growth and capital investment rates. It also presents indicators on the installation of robots and the production of numerically controlled machine tools.

Countries are not limited to the use of their own R&D investments. A great deal of technical know-how flows across national borders, and these flows may have economic and national security impacts. Trends in international technology transfer and trade are discussed in the fourth section of this chapter because of their increasing importance.

International S/T interaction has gained in importance with rising research and development costs and as other countries have improved their capabilities. Thus, it is important that U.S. involvement in international scientific cooperation also be examined. The last section deals with the U.S. role in international scientific cooperation and presents information on the number of foreign S/T students studying in the United States, trends in the number of scientific visitors to U.S. laboratories, and indicators of international co-authorship and utilization of foreign science.

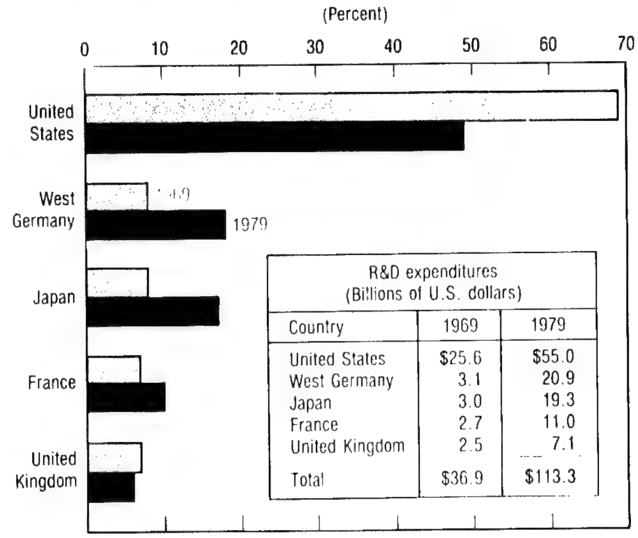
It should be noted that there are often differences between countries in definitions, concepts, and data collection and reporting practices. Therefore, attention is primarily paid to large changes and trends. However, much has been done to institute uniform definitions and standards by international organizations such as the Organisation for Economic Co-operation and Development (OECD) and the United Nations Educational, Scientific and Cultural Organization (UNESCO); thus, the data presented here are broadly comparable.

NATIONAL INVESTMENTS IN RESEARCH AND DEVELOPMENT

Although there is no known optimal level of R&D investment, international comparisons can provide some insight into the question of how much various countries invest in R&D. The United States spends more on research and development (R&D) in absolute terms than any other country except the Soviet Union and about as much as France, West Germany, the United Kingdom, and Japan combined. Large research and development investments have enabled the United States to support a variety of R&D activities in most fields and have contributed to a leadership role in world science. While the United States in absolute terms still spends more on research and development than most other countries, its dominance in investment in world science and technology activities has diminished. (See figure 1-1.) In 1979, the United States spent about as much as France, West Germany, Japan, and the United Kingdom combined. Ten years earlier, U.S. research and development expenditures were more than twice as much as the combined R&D expenditures of these same countries. The U.S. share of total R&D investment among these five countries was about 70 percent in 1969, and about 50 percent in 1979. If expenditures by the Soviet Union are included, the U.S. proportion was close to 30 percent in 1979 and almost 40 percent in 1969. (See appendix table 1-1.)

The number of scientists and engineers engaged in research and development is also higher in the United States than in almost any other country—almost 720,000 in 1982.[1] The Soviet Union is the only country with a larger R&D work force. In 1982, there were between 1.3 and 1.5 million Soviet S/E's in R&D.[2]

Figure 1-1
Distribution of national expenditures on research & development in selected industrialized countries



R&D expenditures (Billions of U.S. dollars)		
Country	1969	1979
United States	$25.6	$55.0
West Germany	3.1	20.9
Japan	3.0	19.3
France	2.7	11.0
United Kingdom	2.5	7.1
Total	$36.9	$113.3

Note. National expenditures are provided in billions of U.S. dollars, at current exchange rates.

See appendix table 1-1 Science Indicators—1982

In 1979, the United States had more S/E's actively involved in R&D than France, West Germany, and Japan combined. The United States had 66 percent of all R&D scientists and engineers in these countries in 1969, 10 years later the U.S. proportion was 57 percent. If the Soviet Union is included in this comparison, the U.S. share was about 25 percent in 1979 and about 35 percent in 1969.[3] This 10-year shift was due not only to more rapid increases of R&D S/E's in each of the other countries, but also to the fact that in the United States the number of S/E's engaged in R&D actually declined through the mid-1970's while all the other countries steadily increased their R&D personnel.

These indicators point out that with respect to R&D investments a more balanced position now exists between three major groups: a) the United States, b) Western Europe and Japan, and c) the Soviet Union and Eastern Europe. As other nations' S/T capabilities improve, the possibilities of technical benefits for the United States resulting from international S/T interactions are increased.[4]

Scientific and Technical Personnel

Since one would not expect each country to invest the same absolute amount in research and development, intensity indicators, which show levels of effort in terms of the size of a nation's economy or population, are necessary. One such way to compare the S/T efforts of different countries is to examine the number of scientists and engineers engaged in R&D as a proportion of the work force. Figure 1-2 shows that these trends roughly parallel those of R&D as a percentage of gross national product (GNP) in the following figure 1-4. The United States has one of the highest

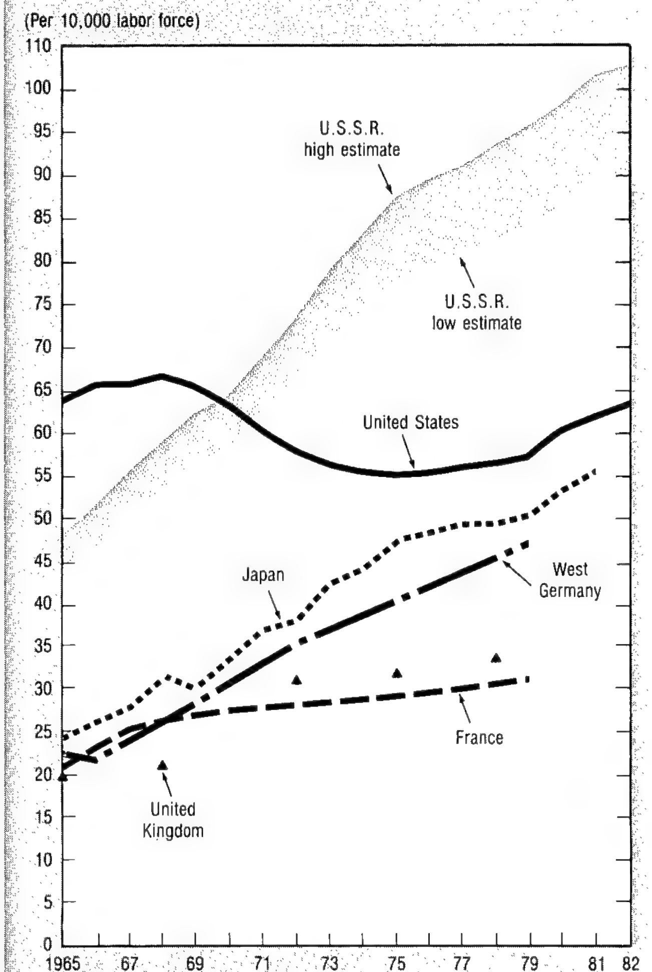
[1] These international comparisons of R&D scientists and engineers are in terms of full-time-equivalent S/E's in R&D.

[2] Comparing U.S. and Soviet scientific personnel statistics is difficult due to differences in data and definitions. Rather than rely solely on Soviet definitions, high and low estimates for the Soviet Union corresponding to U.S. definitions of full-time-equivalent scientists and engineers were developed for this report. The question of research efficiency is not dealt with here, but it is believed that Soviet R&D efficiency is much lower than are the efforts of U.S. scientists and engineers. See refs. 120, 121, and 123.

[3] See appendix table 1-3.

[4] See the International Scientific Cooperation section of this chapter.

Figure 1-2
Scientists and engineers[1] engaged in R&D per 10,000 labor force population by country



[1]Includes all scientists and engineers on a full-time equivalent basis (except for Japan, whose data include persons primarily employed in R&D, and the United Kingdom, whose data include only the Government and industry sectors.)

NOTE: A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data.

See appendix table 1-3. Science Indicators — 1982

proportions of R&D scientists and engineers in the labor force of any country. Six out of 1,000 people in the U.S. labor force are R&D scientists and engineers. The Soviet Union surpassed the U.S. ratio in the early 1970's, reaching a level of 9 to 10 research and development S/E's per 1,000 people in the labor force. Rather than rely on Soviet definitions, high and low estimates for the Soviet Union corresponding to U.S. definitions of full-time-equivalent scientists and engineers are used in this report.

While the concentration of R&D scientists and engineers in the labor force steadily increased in most other countries, the U.S. ratio decreased from the early to mid-1970's due to a drop in the actual number of such S/E's. The U.S. ratio has been increasing since the mid-1970's, as have the Japanese and West German ratios.

The size of the R&D labor force is not the only consideration in measuring a country's R&D capacity. Factors such as level and type of specialization, utilization, or productivity of a nation's S/T personnel are also important.[5] The level and sophistication of scientific and technical training of the general population, as well as of specialists, influence the adequacy of science and technology capabilities and have been the subject of several studies.[6]

It appears that Japan, West Germany, and the Soviet Union have stressed scientific and mathematical proficiency in their secondary educational institutions to a much greater degree than has the United States or the United Kingdom. Japan developed a science-based curriculum after World War II and has very high standards of accomplishment, both for students and science teachers.[7] In an international science test[8] administered to 14-year-olds from 19 countries, Japanese students ranked first in physics, chemistry, and practical science, and first overall. American students ranked fifteenth. However, it should be pointed out that U.S. public high school students won the International Mathematical Olympiad in 1981,[9] an indication that a lower general scientific literacy level may not preclude world-class achievements by gifted individuals.

While the amount of required science instruction in West Germany is roughly equivalent to that in the United States in grades 5 and 6, the amount of physics, chemistry, and biology training far surpasses U.S. requirements in grades 7 through 10. There are variations in the level of physics and chemistry curricula among the three different types of secondary schools in West Germany. However, all three types of German schools provide more mathematics and science training in grades 5 through 10 than do 50 percent of U.S. schools.[10]

The Soviet Union has also put a high priority on precollege science education. U.S. students usually take 9 years to complete arithmetic, while children in other industrialized countries complete arithmetic in 6 years. In the Soviet Union, arithmetic is covered in the first five grades, followed by algebra and geometry. From the fourth grade on, teachers of mathematics in the Soviet Union are highly trained (usually at least to the level of a U.S. master's degree).[11] The top research talent of the Soviet Union has been involved in the development of the science and mathematics curricula for secondary education. In addition, to help develop and encourage a strong interest in science and technology, the Soviet Union publishes a number of high quality popular journals for young people and the general public; many highly qualified and famous mathematicians write for children's mathematics and physics journals that have a large readership, such as *Kvant*.[12] In the Soviet Union, secondary school students take 5 years of compulsory physics, 4 years of chemistry, and 6 years of biology. U.S. students usually take no more than 1 year of each of these three subjects.

[5]See the chapter on Science and Engineering Personnel for a discussion of many of these topics for the United States.

[6]See refs. 72 and 76.

[7]See ref. 77.

[8]This test was administered in 1970. See ref. 11, pp. 159-160. Since then, data from a number of sources show declining achievement by U.S. students in mathematics and science. See ref. 127, pp. 2-3.

[9]See ref. 78, p. 62.

[10]See ref. 80.

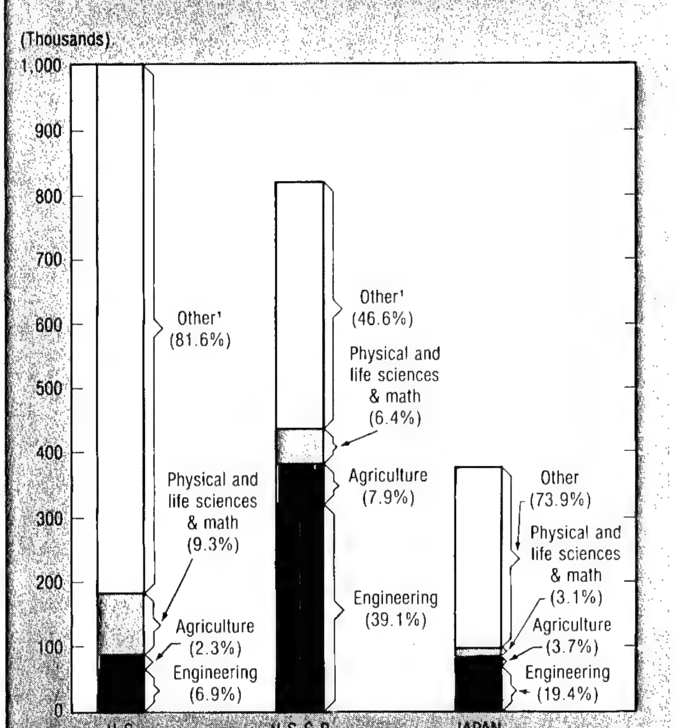
[11]See ref. 78, p. 60.

[12]See ref. 79, pp. 3-7.

These comparisons point out the disparity between the United States and other countries in the amount of time devoted to science and mathematics training of the average skilled worker or military recruit.[13] The importance of scientific literacy continues to grow as our society and economy become more dominated by new technologies. The U.S. population does not seem to have as firm a basic S/T training as do those of other industrialized countries.

Field concentrations of students can provide insights into the relative educational emphases accorded such fields, although it should be remembered that there are likely to be differences in the level and focus of training provided in different countries in a specific field. Figure 1-3 compares the field distribution of first degrees conferred by universities and colleges in the United States, the Soviet Union, and Japan. One-quarter more students graduated in the United States than in the U.S.S.R. in 1980, but only about 190,000 (18 percent) of the U.S. students received their bachelor's degrees in natural science and engineering fields compared with about 440,000 (53 percent) in the Soviet Union. The number of Japanese graduates in natural sciences and engineering (120,000) is somewhat less than that of the United States, with the Japanese proportion of bachelor's degrees in such S/E fields (31 percent) greater than that of the United States. In terms of specific S/E field concentrations, the United States had a higher percent of students graduating in the fields of physical and life sciences and mathematics than did either Japan or the Soviet Union.

Figure 1-3
First degrees conferred by major field of study: 1980



¹Includes social sciences
See appendix table 1-4.
Science Indicators — 1982

One of the outstanding differences between the United States and these other two countries is the greater emphasis placed in these countries on engineering degrees. Almost 40 percent of all Soviet graduates and 19 percent of all Japanese graduates received engineering degrees in 1980. The U.S. proportion of engineering degrees was 7 percent. In the United Kingdom, 13 percent of all bachelor's degrees were granted to engineers in 1979, and in West Germany the share of engineering degrees was 7 percent in 1978.[14]

In 1980, the Soviet Union graduated almost five times as many engineers as the United States, and Japan conferred 16 percent more engineering degrees. Not all of these graduates are employed in engineering. In both Japan and the Soviet Union, national policies promote the training of S/E's in greater numbers than are expected to engage in scientific and engineering professions. In Japan and the Soviet Union managerial positions in government and industry are often filled by engineers.[15] For instance, in Japan, about half of both the senior civil service and industrial directors hold degrees in engineering or related subjects. In the United States, engineers are more frequently managers than are scientists, but engineers still represent only a small proportion of all managers in the economy.[16] Managers with technical backgrounds may be more receptive to technological innovation and change than those with financial or legal backgrounds.[17]

A high concentration of graduates in S/T fields does not automatically impact on overall national S/T capabilities. It is important to examine data on the relative proportions of the college age population in these countries receiving training in natural science and engineering. Appendix table 1-4 shows that 9 percent of the 23-year-olds in the Soviet Union graduated in such S/E fields in 1980—roughly twice the corresponding proportion in the United States (4 percent).[18] In Japan, 8 percent of the college age population are receiving natural science and engineering training.

These trends in scientific and technical training reflect wide differences between the Soviet Union and the United States in the proportion of R&D scientists and engineers in the labor force. However, Soviet training programs are considered to be more narrowly specialized, oriented toward the specific needs of research institutes, and geared toward applied science and development, while U.S. graduates receive a broader based and more flexible theoretical education.[19]

R&D Expenditures

A traditional method used to compare research and development investments of countries of varying sizes is to examine R&D expenditures related to the size of the respective economies. The ratio of national expenditures to the gross national product reflects the proportion of a nation's resources devoted to R&D. R&D/GNP ratios are convenient for international comparisons in another way

[13]See ref. 78, p. 60.

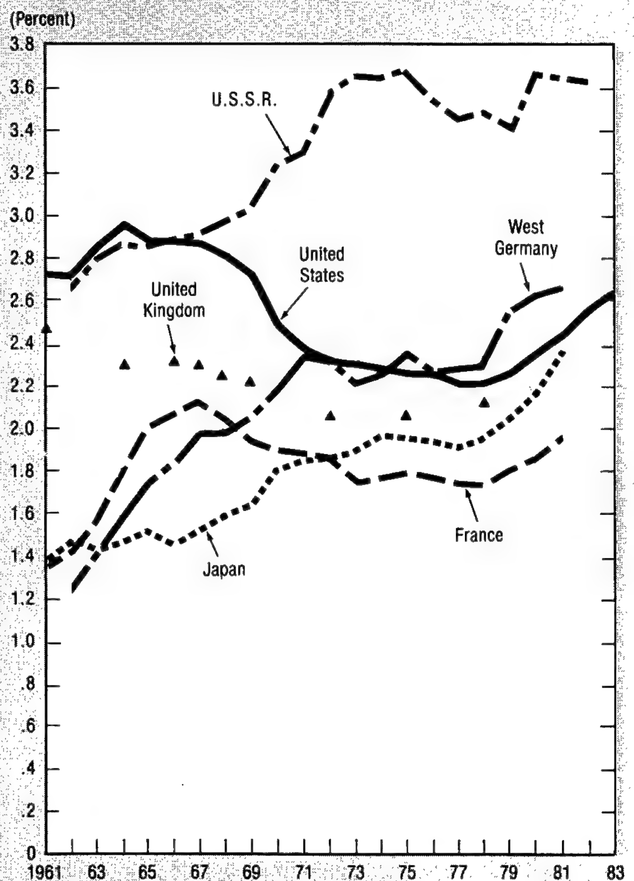
[14]See ref. 75, pp. III-470 and III-465.
[15]See ref. 72, pp. 203-214, and ref. 122.
[16]See ref. 73.
[17]See refs. 74 and 116.
[18]See also ref. 106, pp. 62-69.
[19]See ref. 106, pp. 71-85, and ref. 107, p. 16.

because they attempt to compensate for fluctuating rates of exchange and inflation, which differ considerably from country to country. This adjustment for inflation may only be partial, as there is some evidence that inflation may impact more heavily on industrial R&D than on the general economy.[20] Fully adequate R&D deflators are still generally not available.

The United States devotes a higher proportion of its economy to research and development than almost any other country. Figure 1-4 shows that after a period of stability during the mid-1970's, the ratio began rising again in the late 1970's and is estimated to be almost 2.7 percent in 1983.

Other countries had similar patterns of leveling off in the mid-1970's, with some growth beginning in the late 1970's.[21] The French Government in particular set a political goal of raising its level of investment in research and development,[22] and in 1981 its R&D/GNP ratio reached 2.0 percent. In West Germany, the ratio of R&D to GNP has increased to the point where it is equal to or slightly higher than the U.S. ratio.

Figure 1-4
National expenditures for performance of R&D[1] as a percent of gross national product by country



[1]Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available. Detailed information on capital expenditures for research and development are not available for the United States. Estimates for the period 1972-80 show that their inclusion would have an impact of less than one-tenth of one percent for each year.

NOTE: The latest data may be preliminary or estimated.

See appendix table 1-5. Science Indicators — 1982

Up to the mid-1970's, Japan increased its investments in R&D at a faster rate than its economy was growing. The R&D/GNP ratio held steady in the late 1970's, but is again on the increase, reaching 2.4 percent in 1981. The Japanese Government has suggested that, in order to keep the economy vital in a period of stable growth (as well as to meet other goals), 2.5 percent of GNP should be invested in R&D by 1985 and up to 3 percent by the end of the 1980's.[23]

The R&D/GNP ratio for the Soviet Union has been higher than that of any other country, but it suffered a decline in the late 1970's. This ratio now appears to be increasing again and was an estimated 3.6 in 1982. It is important to note that except for the Soviet Union (for which data may not be strictly comparable), R&D per GNP in these countries varied within the narrow range of 2.0 percent to 2.7 percent in recent years, despite earlier fluctuations.

An examination of annual growth rates of national R&D expenditures in constant terms shows that the United States lagged behind most other countries during the 1970's. Appendix table 1-2 shows that in the mid- to late 1970's, the U.S. growth rate of R&D expenditures in real dollars averaged 2 percent compared to 6 percent for Japan, and 4 percent for West Germany.

Civilian R&D Expenditures

Although defense and space R&D have important economic impacts,[24] civilian R&D probably is more directly relevant to economic growth and other social goals.[25] Defense and space R&D are aimed primarily at attaining other public goals (e.g., national security). Figure 1-5 presents national trends in (nonspace) civilian R&D expenditures[26] as a percent of GNP. Over the past decade, West Germany and Japan have had the highest ratios among these five countries.

Investments in civilian R&D in West Germany and Japan have generally risen at a faster rate than their economies and reached 2.5 percent and 2.3 percent respectively in 1981, compared with 1.7 percent for the United States. Post World War II restrictions limited defense R&D expenditures in these two countries. Therefore, it is not surprising that they have a high concentration of R&D expenditures in civilian areas such as telecommunications, energy production, and manufacturing. Another factor influencing the high rate of civilian R&D expenditures is the major role that industry has played in supporting R&D, as will be discussed in the next section.[27]

[21]The United States has kept pace with the R&D investments of other industrialized nations since the mid-1970's. For further discussion of these trends, see ref. 128, pp. 10-12.

[22]See ref. 1, p. 140.

[23]See ref. 1, p. 133.

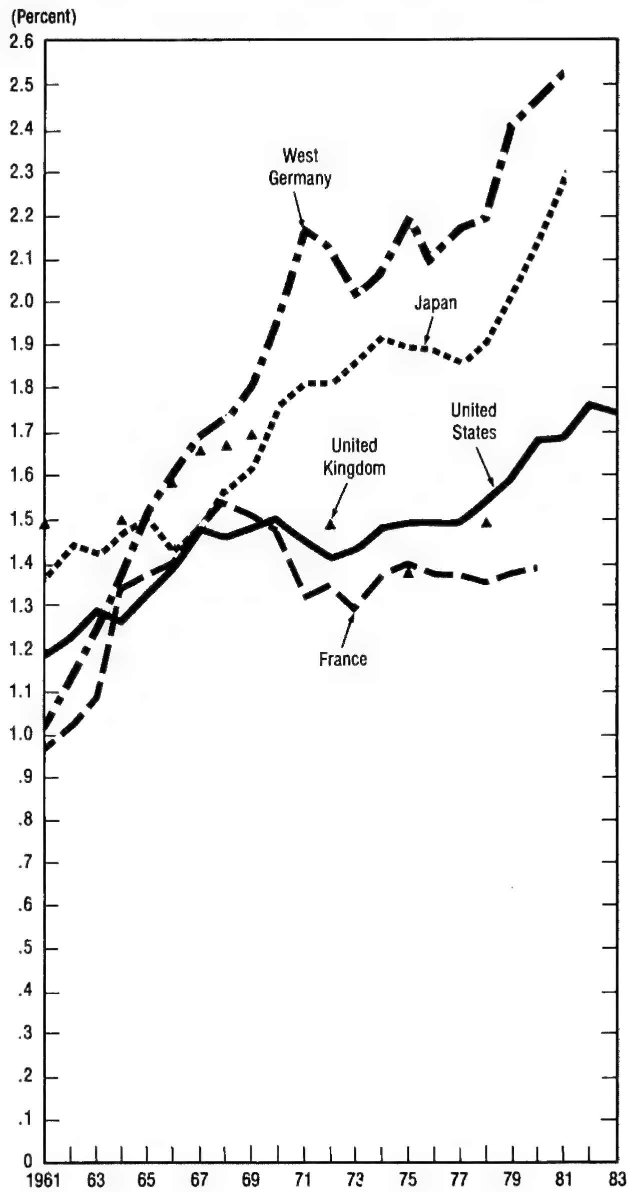
[24]These impacts can be both positive and negative. See ref. 21 and ref. 22, pp. 22-63.

[25]See ref. 23 for a discussion of the rationale and history of Government support for civilian R&D.

[26]Civilian R&D expenditures as defined here include all privately funded R&D as well as publicly funded nondefense and nonspace R&D.

[27]See appendix table 1-8.

Figure 1-5.
Estimated ratio of civilian R&D expenditures to gross national product (GNP) for selected countries



[1]National expenditures excluding Government funds for defense and space R&D.
See appendix table 1-6. Science Indicators — 1982

The United States has a lower civilian R&D-to-GNP ratio than Japan and West Germany. This is influenced by the fact that Government funds have constituted a majority of the Nation's R&D expenditures until recently, and about 65 percent of the Government effort is in defense or space R&D. The United States carries major international defense obligations and these obligations require large R&D investments for future capabilities.

After a period of stability in the mid-1970's, the U.S. civilian R&D ratio began a growth period in the late 1970's, with increased Federal Government funding in areas such as energy, health, and environmental R&D and increased industrial support of R&D.[28] It has continued to increase along with total R&D expenditures, and by 1983, the U.S. civilian R&D expenditure ratio reached almost 1.8 percent. Even though the U.S. civilian R&D/GNP ratio is lower than those of West Germany and Japan, in absolute dollars the U.S. investment is greater. In 1980, U.S. civilian R&D expenditures equaled $49.8 billion compared to the equivalent of $18.8 billion in West Germany and $25.1 billion in Japan.

Government-Industry Funding Patterns

Countries differ in their priorities, policies, and practices. The differences in funding patterns between public and private sources can affect the amount of a nation's civilian R&D and the contribution of R&D to economic growth. There is evidence that privately financed R&D expenditures make a greater direct contribution to productivity growth than do publicly financed R&D expenditures.[29] This is natural since industrial R&D is generally aimed at projects more likely to materialize into commercial use (and thus be a direct influence on the economy). Government-supported R&D does have a social economic impact, but it is usually long term or indirect.[30] Government R&D expenditures are often aimed at areas unlikely to receive support from the private sector, but for which the Government has a genuine interest or role. Such projects would include those that have high risk, high social benefit, or high costs, or those where the Government itself is a consumer of the results. For instance, in the United States, the Federal role in supporting R&D has been shifted to an emphasis on basic research rather than short-term applied research or development except in such areas of Government concern as defense, space, environmental regulation, and in some heavily regulated industries such as nuclear research.[31]

Government R&D Funding by Objective. Examination of total Government R&D funding by specific national objectives (excluding general university funds) points out major national differences in R&D priorities.[32] Figure 1-6 shows that defense R&D is the most important governmental funding priority in the United States, the United Kingdom, and France. In contrast, Japan only spends 5 percent of its Government R&D budget on defense and West Germany only 15 percent. These two countries spend about one-fourth and one-fifth, respectively, of their Government R&D funding on energy R&D and about 12 percent in areas of industrial development. Japan also spends nearly one-fourth of its specified Government R&D support on agricultural projects.

The U.S. Government devotes a larger share (15 percent) of its budget to space and aeronautical R&D than do other OECD (Organisation for Economic Co-operation and Development) nations. Japan spends 12 percent of its R&D funds on space, and France and West Germany each spend 7

[28]See ref. 25 and the chapter on Support for U.S. Research and Development.

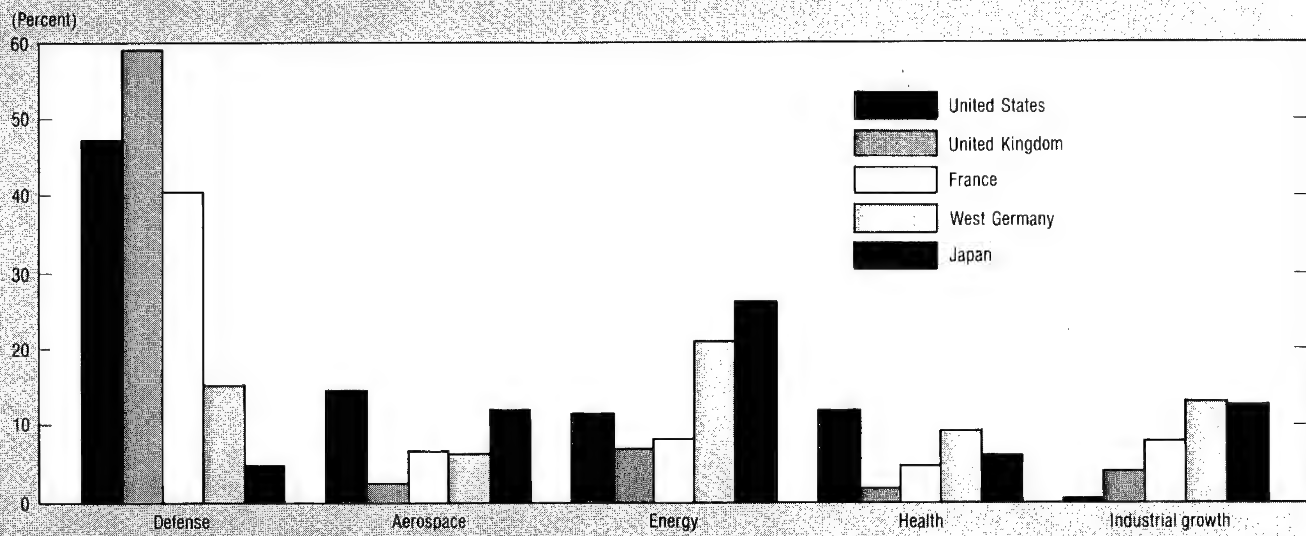
[29]See ref. 5, pp. B5-B20.

[30]See ref. 3.

[31]See ref. 6, pp. 4-8.

[32]Unlike the United States, in most OECD countries just under half of the government R&D funds go to general university research. The distributions of government funds presented here are on the basis of those government funds oriented towards R&D programs other than general university research.

Figure 1-6.
Distribution of government R&D expenditures among selected objectives[1] by country: 1980



[1]Excluding general university funds.
See appendix table 1-7

Science Indicators — 1982

percent, and the United Kingdom spends 2 percent. While the United States is seen as the world leader in this area, other countries (in addition to the Soviet Union) are becoming more prominent.[33]

The U.S. Government also differs from other countries in the priority it gives to health research—over 12 percent of the U.S. Government's R&D support is in this area. This is consistent with the high priority that the American public has afforded health research.[34] The United States is responsible for about 70 percent of all the health R&D conducted by OECD countries.

After the 1973 energy crisis, the United States significantly increased public support of energy R&D. U.S. Federal funding in this area increased sixfold from $0.6 billion in 1973, to $3.6 billion in 1980. Funding has subsequently dropped to an estimated $2.6 billion in 1983.[35] Appendix table 1-7 shows that energy R&D now represents 11 percent of U.S. Federal R&D funds compared with about 4 percent in the early 1970's. However, Japan and West Germany spend a larger percentage of their funds on energy R&D, which constitutes 26 percent of public R&D funds in Japan and 21 percent in West Germany. Nuclear energy receives the lion's share of energy R&D funds in all of these countries except the United States.[36]

Industrial R&D. Table 1-1 presents R&D funding patterns between countries and shows that industry has been a more dominant direct contributor in Japan than in other countries (although the Japanese Government also provides a great deal of support through indirect measures). In contrast, the U.S. Government has been responsible for supporting over half of all the Nation's R&D effort.[37] However, by 1979 the responsibility for funding research and development was more evenly divided than before, not only in the United States, but in West Germany and France as well. Governments can and do contribute to R&D in ways other than direct funding as is discussed later.

Table 1-1. Percent of gross expenditures for R&D from private sources, for selected countries: 1970 and 1979

Country	1970	1979
Japan	59	59
West Germany	53	55
United States	38	46
France	37	44
United Kingdom[1]	42	43

[1] 1979 data for the United Kingdom are from 1978.

NOTE: The preponderance of the remaining non-private funding of R&D is accounted for by the Governments of these countries.

SOURCES: Organisation for Economic Co-operation and Development, *Science and Technology Indicators Basic Statistical Series—Volume B* (Paris: OECD, 1982), and *Recent Results Selected R&D Indicators 1979 to 1983* (Paris: OECD, 1983).

Science Indicators—1982

Much larger differences in funding patterns appear when one examines industrial R&D performance. Appendix table 1-8 shows that Japanese industry supports essentially all of its research with its own funds. Over three-fourths of West Germany's industrial R&D funds are provided by

[33]For instance, the French remote-sensing satellite SPOT, scheduled for implementation in 1984-1985, may have more advanced capabilities than the U.S. Landsat system. See ref. 16, p. 5.

[34]See the chapter on Public Attitudes Toward Science and Technology.

[35]See the chapter on Support for U.S. Research and Development, appendix table 2-12, and ref. 108.

[36]See ref. 1, pp. 90-93.

[37]See the chapter on Support for U.S. Research and Development for further discussion.

industry itself. In the United States, the pattern has been quite different. In 1970, the United States had the lowest percentage of industry-funded R&D investment of all of these countries. By 1979, U.S. industry had increased its share of industrial R&D funding to 67 percent, nearly as great as the French industry's 71 percent support of its own research.[38]

U.S. Government support of industrial R&D has been significant. The U.S. and United Kingdom Governments both have major contracts with aerospace and electronics industries to support their substantial defense and aerospace programs. The Government-financed portion of industrial R&D declined during the late 1970's to 30 percent in both countries, but these trends are expected to reverse as defense spending expands.[39] The French Government's industrial R&D support is heavy in defense areas as well.[40]

Government funding patterns can affect the R&D intensity of industries and the concentration of R&D by industries. One measure of R&D intensity is the ratio of total industrial expenditures for research and development to the domestic industrial product (DPI).[41] Appendix table 1-9 shows that the United States and West Germany have the highest ratios of industrial R&D to DPI at about 1.9 percent. France and Japan have the lowest ratios (1.4 percent). West Germany and Japan are the only countries in this group to increase their industrial R&D intensity over the period.

The above ratios include large governmental support for industrial R&D by the United States and the United Kingdom. When public funding is factored out, and industry's own funds are examined, the United States has a lower industrial R&D-intensity ratio (1.3 percent) than does Japan (1.4 percent) or West Germany (1.6 percent).[42]

Another way to compare a nation's industrial R&D effort is to examine industries in which the R&D is concentrated. Appendix table 1-10 shows that in 1979 about 70 percent of U.S. private industrial R&D is concentrated in those industries which are often considered R&D-intensive.[43] West Germany has a slightly higher percentage of its industrial R&D is in these selected industries. Japan has the lowest proportion of industrial R&D in these selected industries as a whole. Looking at specific industries, the highest proportion of Japanese industrial R&D is in electrical and electronics industries (23 percent) followed by the chemical industries (20 percent). More than one-quarter of West German industrial R&D is in each of these two industrial groups. In the United States, industrial R&D is more evenly spread across these R&D-intensive industry groups, and a larger percentage is financed by industry itself in the aerospace industries (9 percent) and computer industries (12 percent) than in any of the other countries examined here.

If Government support for industrial R&D is included (see appendix table 1-11), the United States has the highest percentage of total R&D in these selected industries (75 percent) followed by the United Kingdom (73 percent). In fact, about 70 to 75 percent of all industrial R&D is performed in these industries in four of the five countries examined. Japan's proportion was much lower at 55 percent largely because it has a negligible industrial effort in aerospace. Inclusion of Government-financed industrial R&D raises the U.S. aerospace R&D concentration to 21 percent, higher than any other industry group.

In addition to direct funding, Government can support (or discourage) R&D in a myriad of ways, such as tax incentives,[44] fiscal and monetary policies affecting interest rates and the availability of capital, regulatory policies, procurement practices, patent policies, and antitrust policies. General economic policies aimed at reducing inflation, or unemployment can have an important impact on the amount of industrial R&D conducted.

The U.S. Economic Recovery Tax Act of 1981 was intended to revitalize American industry and general economic conditions and to provide incentives for private R&D investments. For instance, a new 25 percent tax credit on incremental R&D expenditures was implemented to encourage greater industrial R&D expenditures.[45]

In Japan, the Government provides tax exemption for extensive R&D investments and for income derived from technology export, as well as low interest loans for R&D investments. Extensive interaction exists between the Japanese Government, banks, and industries.[46]

Another technique that the Japanese Government has used to stimulate innovation is the sponsorship of research consortia which bring together public and private sector scientists (including researchers from rival companies) to concentrate on a particular high priority effort. An important example is the Very Large Scale Integration (VLSI) project undertaken between 1976 and 1980 at an estimated budget of about $360 million (70 percent financed by the Government) over 4 years.[47]

In West Germany, there is also a high level of cooperation between industry and the Government in an effort to reduce R&D costs for private firms and to encourage innovation in certain priority areas. For instance, interest-free forgivable loans for up to 50 percent of the commercial development costs are provided by the Government for certain promising new technologies.[48] These types of policy measures may be as effective in stimulating R&D and innovation in industry as direct Government support.[49]

[38]See ref. 2, p. vii. Also see the chapter on Industrial Science and Technology.

[39]See ref. 1, p. 50.

[40]See ref. 1, p. 85-87.

[41]Research and development as a percentage of sales or as a percentage of value added are also often used as measures of R&D intensity. Domestic industrial product (DPI) is the value added measure used by the Organisation for Economic Co-operation and Development. DPI is the sum of the value added of resident producers in industry.

[42]See ref. 1, p. 47.

[43]The industries shown in appendix table 1-10 have an average of 25 S/E's engaged in R&D per 1,000 employees and total R&D funding amounting to at least 3.5 percent of net sales. See the section on technology transfer and trade of this chapter for a more complete discussion of the topic.

[44]Countries differ greatly in their tax provisions related to R&D and innovation. For a detailed comparison, see ref. 26.

[45]See ref. 16, p. 34.

[46]See ref. 27, pp. 140-152.

[47]See ref. 34, pp. 34-36.

[48]See ref. 28.

[49]See refs. 29, 30, 31, and 33. Between 1970 and 1977, Britain attempted to orient government-sponsored civilian R&D to meet national needs, but the effort has not been a total success. This experience points out the difficulties a government has in identifying, communicating, and implementing the best plan for industrial R&D. Also see ref. 32.

OUTPUTS OF R&D

It is difficult to quantify the results of R&D, much less its value to the economy or to the society as a whole. Two frequently used output measures of R&D efforts are scientific and technical literature and patents. In this section, the U.S. position in world science is measured in terms of the number and relative influence of U.S. scientific and technical articles. U.S. and foreign patenting trends are examined as indicators of inventive activity.

Scientific Literature

Scientific literature is one of the major direct outputs of research. Scientific and technical findings are generally published in professional journals and thus add to the body of world scientific knowledge since scientists and engineers of all countries generally have access to this body of knowledge. The findings may stimulate further research or be used in a variety of practical applications in other fields, many of which are unanticipated at the time of the original research. Thus, publications can be considered an intermediate output as well as a final output of research.

Publication counts have long been accepted as output indicators of scientific activity,[50] although they do not indicate the importance of individual publications. However, there are several limitations in using publication counts for international comparisons. National publication characteristics may be affected by the number of journals published in that country or language or by editorial practices such as space availability within each journal and publication cost policies. However, since about three-fourths of the literature represented in the indicators below was published in journals of countries other than the authors' own,[51] differences in countries' publication characteristics should have little impact on international scientific literature indicators, as a whole. This section presents literature indicators based on a set of over 2,100 highly cited or influential scientific and technical journals.[52] Even though there may be differences in the theoretical or practical importance of individual articles, critical review prior to their publication in these influential journals helps to ensure a standard of quality and significance.[53]

U.S. scientists and engineers are responsible for a large portion of the world's scientific literature—37 percent for all eight fields together (clinical medicine, biomedicine, biology, chemistry, physics, earth and space sciences, engineering and technology, and mathematics) in 1980. Table 1-2 shows that the highest U.S. share in 1980 was in the field of clinical medicine (43 percent), and the lowest in chemistry (21 percent).

The U.S. proportion of the world's most influential S/T literature in all fields combined declined slightly from 1973 to 1980, and dropped in six out of eight of the individual fields. Mathematics experienced the largest declines, both in terms of shares and actual numbers. The U.S. share of mathematics literature went from 48 percent in 1973 to 40 percent in 1978 where it remained through 1980, and the number of U.S. mathematics articles decreased 36 percent over the 7-year period, whereas non-U.S. articles in this field dropped only 23 percent. The number of U.S. engineering and technology publications also declined—29

[50]An early but important discussion of the use of publications as output indicators can be found in ref. 35. Also see ref. 36.

[51]The author's country is determined by the location of the author's organization, and a journal's country is defined as the country where it is published.

[52]The data base is developed from the *Science Citation Index* (SCI) Corporate Tapes of the Institute for Scientific Information. For journals published in the industrialized nations, the *SCI* appears to be a fairly well-balanced data base for the core of physical and biological sciences, but there are still differences in national coverage of fields, especially for countries with non-Roman alphabets such as the Soviet Union (see ref. 37 and ref. 38).

[53]The set of journals examined has been held constant for the period 1973-1980 in order to facilitate more valid longitudinal comparisons. The growth of publications in journals that have appeared since 1973 (or which are not considered "influential," as the term is used here) is not reflected in these indicators. Even when an expanded set of journals is examined, the U.S. share remains about the same—36 percent compared with 37 percent for the "fixed" journal set.

Table 1-2. U.S. proportion of the world's S/T articles[1] by field: 1973-80
(Percent)

Field[2]	1973	1975	1977	1978	1979	1980
All fields	38	37	37	38	37	37
Clinical medicine	43	43	43	43	43	43
Biomedicine	39	39	39	39	40	40
Biology	46	45	42	42	43	42
Chemistry	23	22	22	21	21	21
Physics	33	32	30	31	30	30
Earth and space sciences	47	44	45	45	45	42
Engineering and technology	42	41	40	39	41	39
Mathematics	48	44	41	40	40	40

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-13 for a description of the subfields included in these fields.

See appendix table 1-12

Science Indicators—1982

percent—compared with 22 percent for the rest of the world and the U.S. proportion of publications in this field dropped from 41 percent in 1979, to 39 percent in 1980.

The number of U.S. publications in biomedicine increased 9 percent, helping to make biomedicine the only field in which the U.S. annual share of publications actually rose over the 1973-1980 period. The category of biomedicine includes such fast growing fields as genetics, physiology, biomedical engineering, cell biology, biochemistry, and microbiology.[54] The number of U.S. articles published in the field of clinical medicine rose 6 percent over the 1973-1980 period, but because publications from the rest of the world also rose by about the same amount, the U.S. share of literature in clinical medicine remained at 43 percent. The fields of biomedicine and clinical medicine represent more than half of all the articles in this scientific literature data base and so helped to support the overall U.S. share, despite declines in the number of U.S. articles in the other six fields. In contrast, the number of non-U.S. articles increased in the 7-year period in six of the eight fields, declining only in mathematics, and engineering and technology.

Science is a cumulative endeavor, with scientific progress building on previous research.[55] One of the ways that S/E's acknowledge the contribution of former research and seek to differentiate or support their own findings is through citing previous publications. Under the assumption that the most significant literature will be more frequently cited than routine literature, citation indicators are used to measure the influence and quality of research. Some articles may be cited for purposes of criticisms, but these are definitely a minority. Other articles may not be readily available and therefore infrequently cited. This situation is generally not the case for the publications in the journal set examined in this report.[56]

U.S. authors are responsible for a large portion of the world's influential scientific literature, and it is therefore more likely that U.S. science and technology literature would be widely used and highly cited throughout the world. Table 1-3 presents citation ratios for U.S. articles adjusted for the size of the literature base; a ratio greater than 1.00 represents more citation and influence than could be expected.[57] By this measure, U.S. scientific and technical literature is disproportionally influential, being cited 45 percent more than could be expected. In fact, in each of the eight S/E fields examined, U.S. literature published in 1978[58] was cited more frequently than could be explained by the size of the U.S. literature base. U.S. chemistry and physics articles were particularly highly cited (88 percent and 57 percent, respectively, above what could be expected).

Even when U.S. scientists' and engineers' usage of their own literature is factored out, three fields are more influential than could be expected from the size of the U.S. share of the world's literature. In seven of eight fields, U.S. literature is more highly cited than other nations' S/T literature when self citation rates are discounted. U.S. literature in chemistry is still the most highly cited of all the S/E fields examined here, followed by earth and space sciences and physics.

Table 1-3. Relative citation ratios[1] for U.S. articles[2] by field: 1973 and 1978

Field[3]	1973	1978
World citations to U.S.:		
All fields	1.40	1.45
Clinical medicine	1.35	1.39
Biomedicine	1.42	1.36
Biology	1.07	1.09
Chemistry	1.66	1.88
Physics	1.53	1.57
Earth and space sciences	1.39	1.46
Engineering and technology	1.28	1.33
Mathematics	1.23	1.37
Non-U.S. citations to U.S.:		
All fields	1.01	.96
Clinical medicine	.99	.98
Biomedicine	1.07	.90
Biology	.67	.57
Chemistry	1.17	1.25
Physics	1.15	1.04
Earth and space sciences	1.06	1.11
Engineering and technology	.86	.79
Mathematics	.85	.90

[1] A citation ratio of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U.S. articles for that year. For example, the U.S. chemistry literature for 1973 received 66 percent more citations from the world literature of later years than could be accounted for by the U.S. share of the world's chemistry articles published in 1973.

[2] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see Appendix table 1-12.

[3] See appendix table 1-13 for a description of the subfields included in these fields.

See appendix table 1-14.

Science Indicators—1982

Over the 1973-1978 period, non-U.S. citations of U.S. literature increased in three fields—chemistry, earth and space sciences, and mathematics—but decreased overall and in four individual fields—biomedicine, biology, physics, and engineering and technology. The largest decline in citations occurred in the field of biology, which was already the least influential field in U.S. research literature according to this measure. U.S. biology (in contrast to biomedicine) articles appearing in 1978 have been cited by non-U.S. authors only a little more than half as much as what could be expected from the size of the U.S. body of literature in biology.

Foreign Patenting in the United States

Patent data can be used as output indicators of inventive activity. Although there are some limitations there are many advantages in using patent data: they are available for many different countries, at very disaggregated levels of detail, and for extended periods of time. Numerous studies support their value as output indicators.[59]

[54] Appendix table 1-13 lists all the subfields associated with each of these fields and shows the number of U.S. and world articles in each.

[55] See the chapter on Advances in Science and Engineering for a description of selected significant scientific achievements that offer interesting examples of how science evolves.

[56] See refs. 37 and 38.

[57] Citation counts are taken from publications after the year being cited. Publication counts are those of the cited year through 1980. The relative citation ratio is derived as follows, for each major field separately: U.S. citations as a percentage of all citations to a given year divided by U.S. publications as a percentage of all publications of the cited year.

[58] 1978 is the latest year for which reliable subsequent citation ratio patterns can be determined.

[59] See refs. 39, 40, 41, and 110.

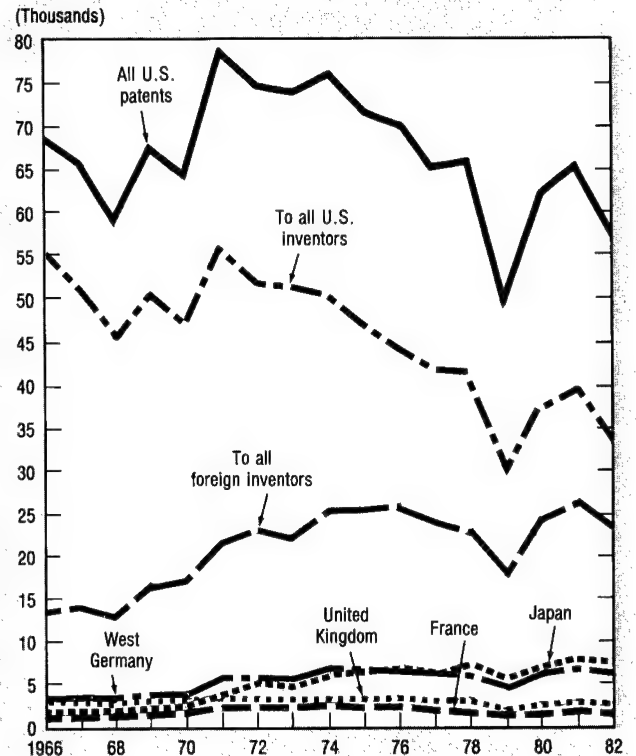
Because patents represent a stage in the innovation process prior to engineering design production and market introduction, patent data are thought to indicate inventive activity. Patent data do not reflect total inventive activity because not all new ideas or inventions are patented or patentable, and those inventions that are do not necessarily reflect the same level of technical or economic value. Patent laws and practices vary from country to country, but patent laws, perhaps more than any other laws, have been harmonized internationally.[60] Foreign-origin patents within a given country represent approximately the same degree of originality as domestic patents because they pass through the same screening process and must meet the same requirements of novelty. In fact, foreign-origin patents may be more significant than the average patent in terms of technical or economic value of the invention, since an invention that seems to have little technical or commercial value would generally not merit the expense and time required for international patenting. There is some evidence that foreign patenting also can be an indicator of market interest as well as of inventive activity.[61] The indicators presented here generally focus on foreign patenting activities in the United States and U.S. patenting activities abroad.

Figure 1-7 shows that since 1971 U.S. domestic patenting has decreased by about 40 percent. Foreign patenting in the United States increased between 1971 and 1974, but has remained relatively level since. Most of this increase in foreign patenting can be attributed to Japanese inventors; the number of Japanese-origin patents granted by the United States has steadily increased and more than doubled from 1971 to 1982. West German patenting in the United States increased through the mid-1970's and has been somewhat level since. In 1982, over half of all foreign-origin patents granted by the United States went to inventors from Japan (34 percent) and West Germany (23 percent). Foreign-origin patents now constitute over 40 percent of all U.S. patents, compared with 29 percent a decade ago.

The use of trade secrets as alternatives to patenting may have increased in the United States, but for obvious reasons it is impossible to count them. The propensity to use patents or to use trade secrets differs among industries, firms, and inventions. The propensity to patent is highest in industries, such as the drug industry, where technical advances can be easily copied by competitors, and lowest where they are technically difficult to imitate or where technological advances occur very rapidly. Therefore, one would expect that trends in patenting activity would vary among industries and product fields. However, this does not seem to be the case. Patenting activity by U.S. inventors has decreased in almost all product fields,[62] and therefore the U.S. drop in patenting may actually indicate a decrease in the production rate of U.S. inventions rather than being primarily attributable to increased use of trade secrets.

Many other countries also have experienced a decline in their domestic patenting, particularly France and the United Kingdom. In sharp contrast, domestic patenting has increased over 70 percent in Japan between 1971 and 1977 and in West Germany rose 40 percent from 1971 to 1978. Since the late 1970's, domestic patenting has leveled off or decreased in these two countries. (See appendix table 1-18.)

Figure 1-7.
U.S. patents granted to inventors from selected countries by data of grant and nationality of inventor



NOTE: The actual number of U.S. patents issued in 1979 was artificially low due to lack of funds for printing approved patents.
See appendix table 1-15.
Science Indicators — 1982

Studies show that there is a significant correlation between foreign patenting activity in the United States by selected OECD countries and industrial R&D in those same countries. The correlations are especially high for the manufacturing sector as a whole, and for the chemical, electrical and electronic, and nonelectrical machinery industries.[63] High correlations have also been found between export shares of 10 OECD countries and their patenting activity in the United States, particularly in chemicals, capital goods, and durable consumer goods. This suggests that inventive activity is an important element in international competitiveness.[64]

The propensity to patent in another country is thought to be related to the perceived market potential of that country.[65] Foreign patenting activity in the United States is probably influenced by certain attractive characteristics of the U.S. patent and market system. U.S. patents provide protection for the introduction of a new technology or

[60] A recent investigation of the causes of U.S. patenting activity abroad found that differences in patent laws were not a significant factor influencing foreign patenting. See ref. 46.

[61] See ref. 42.

[62] Declines occurred in most product fields. Clear increases in patenting activity occurred only in the product fields of drugs and medicines, plastics, and agricultural chemicals. Soaps and perfume and engines and turbines registered some growth over the period.

[63] See ref. 43.

[64] See ref. 44.

[65] See ref. 42.

product into the large homogeneous U.S. market. However, a recent study comparing domestic patenting activity with foreign patenting activity across 38 industrial sectors in the United Kingdom, Germany, France, and the United States concluded that "market pull" or economic factors were not the major factors influencing foreign patenting. This conclusion was based on a close inter-industry correlation between foreign and domestic patenting, together with the close inter-country correlations between foreign patenting and R&D investments discussed above.[66]

It can be argued that both market pull and technology push are strong forces influencing foreign patenting activity. Perhaps economic promise is a strong determinant factor of the level of foreign patenting in general, while technological inventiveness determines product areas in which foreign patenting occurs.

In the period 1979-1981, in each of four different product fields, almost half of all U.S. patents granted were to foreign inventors: drugs and medicines, primary metals, aircraft and parts (including engines and turbines), and textile mill products. (See table 1-4.) Foreign inventors were granted 40 percent or more of the U.S. patents in four additional fields. Some of these foreign patents are assigned to U.S. organizations or individuals. For example, although 49 percent of all U.S. patents in the field of drugs and medicines are granted to foreign inventors, 14 percent of these foreign-origin patents are actually owned by U.S. entities. U.S. ownership of foreign-origin patents is significant in the product fields of chemicals, drugs, communication equipment, and petroleum and natural gas extractions. Many of these are associated with industries in which there are high levels of U.S. direct investment abroad. It is very possible that U.S. research efforts abroad produced many of these patented inventions and that they are produced by foreigners working for U.S. firms.

Table 1-4. Percentage of total U.S. patents granted to foreign inventors by product field: 1979–81 period.

Product field	Foreign	U.S.–owned foreign[1]
Drugs and medicines	49	14
Primary metals	49	4
Aircraft and parts	49	3
Textile mill products	48	8
Chemicals, excluding drugs and medicines	44	12
Professional and scientific instruments	42	6
Nonelectrical machinery	42	4
Motor vehicles and other transportation	42	3
Communication equipment and electronic components	40	13
Food and kindred products	39	9
Electrical equipment except communication equipment	38	8
Stone, clay, glass and concrete products	37	7
Rubber and miscellaneous plastic products	37	6
Fabricated metal products	33	6
Petroleum and natural gas extraction and petroleum refining	20	15

[1] Patents with a foreign resident inventor that are assigned to a U.S. organization, divided by the total number of U.S. patents with a foreign resident inventor.

SOURCE: Compiled from information in Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of the Patent Output of U.S. Industry, (1963–1981)*, June 1982.

Science Indicators—1982

Appendix table 1-18 shows the number of U.S. patents by product field granted to inventors from 15 countries. At least one-half of all the foreign patenting in each major product field is dominated by only three countries—usually West Germany, Japan, and the United Kingdom—and only five countries are responsible for about three-fourths of all the foreign-origin patents in each category. U.S. foreign-origin patents are also highly concentrated in terms of product fields, with more than half (53 percent) in two major product fields—nonelectrical machinery and chemicals (except drugs and medicines). This pattern is similar to the U.S. domestic patenting experience where 45 percent of all domestic patents are granted in these same two fields.

In the early 1970's, West German inventors received the largest number of U.S. patents granted to foreigners, and were responsible for about one-fourth of all U.S. foreign-origin patents. Japan surpassed West Germany in 1975 as the foreign leader in the overall number of U.S. patents granted to its inventors and by 1981 was the foreign leader in 10 of the 15 major product fields examined.

Figure 1-8 presents country concentrations of the foreign-origin patents for selected fields in 1981. Examination of recent foreign patenting activity in product fields often associated with R&D-intensive industries highlights the current dominance of Japanese inventors as the foreign leaders in many of these important fields. Japanese inventors had over 40 percent of all U.S. foreign-origin patents in three of these fields—communication equipment; aircraft and parts; and professional and scientific instruments—and 37 percent in the field of electrical equipment. Although these data are representative of only 1 year, they can be used as leading indicators of country emphases in these technologically and economically important areas. The high percentages of Japanese-originated patents in these product fields, which are often associated with R&D-intensive industries, parallels their penetration of the U.S. market.[67]

Highly cited patents can be used as an indicator of significant inventions. Recent research[68] has shown that the commercial or technical importance of a patent is likely to be related to the degree of citation by patent examiners of subsequently issued patents. It was determined that a set of important patents (underlying products which received the Industrial Research and Development IR 100 award) were cited two and one-half times more frequently on the average than randomly selected patents. U.S. patents were categorized in terms of the number of subsequent citations each received. This was an attempt to resolve the problem of the inability of patent counts to differentiate between significant patents and those which are not so important.

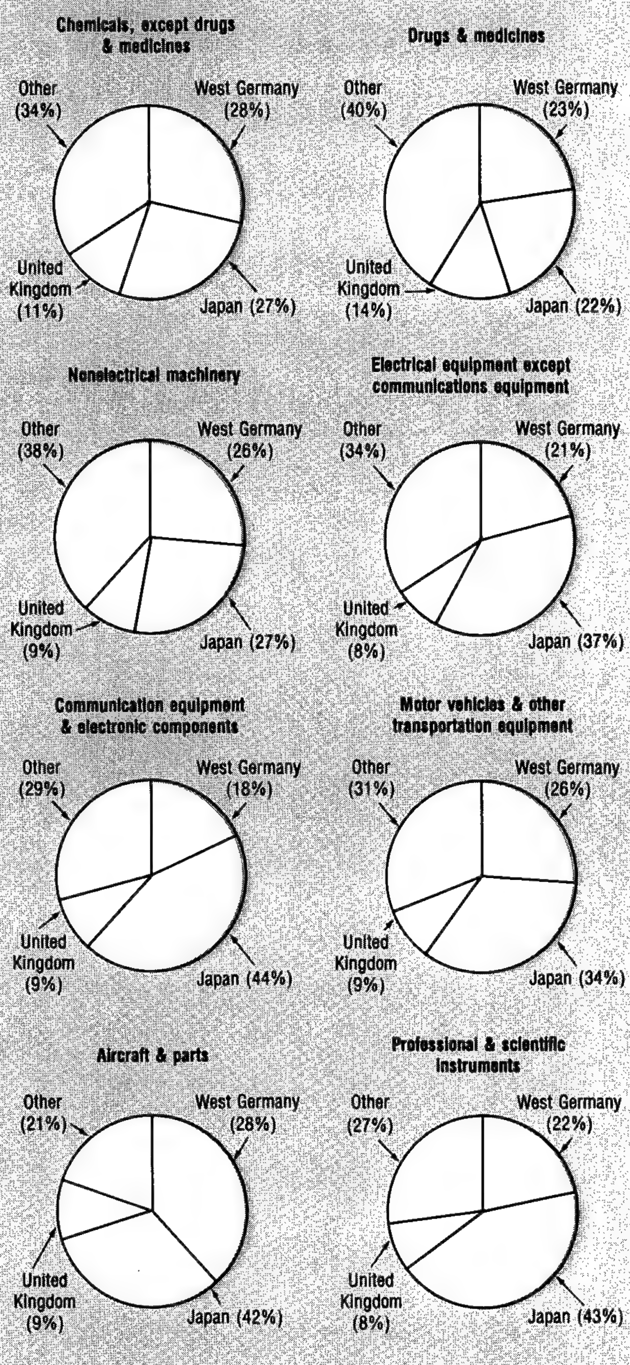
Patents appearing in the most recent years would not have time to accumulate citations. Therefore, the most recent year for which full patent citation data are feasible is 1977. Examination of table 1-5 shows that in 1977, the U.S. proportion of highly cited patents was larger than foreign-origin patents in the fields of ordnance (except missiles), primary metals, and food and kindred products. U.S. inventors also had a larger percentage of highly cited patents

[66] See ref. 45, pp. 14-17.

[67] See figure 1-16 in the R&D-intensive trade section.

[68] See ref. 120.

Figure 1-8
Share of foreign patenting in the United States for the three most active countries in selected product fields: 1981



See appendix table 1-17

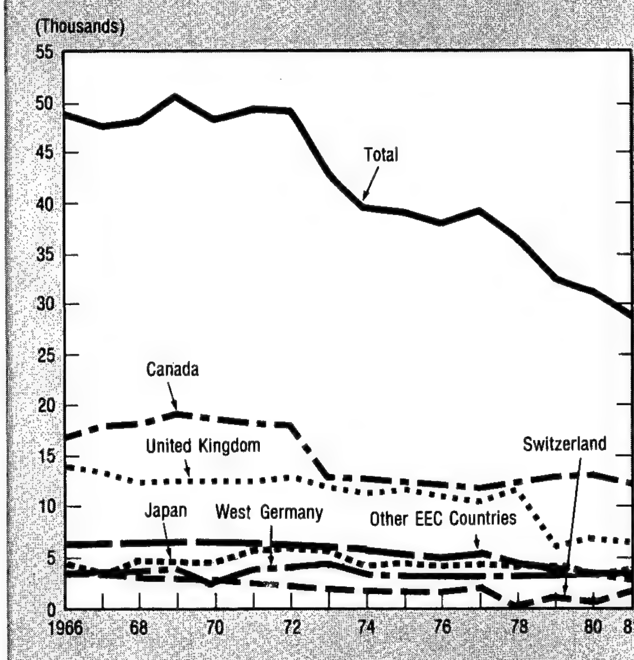
Science Indicators — 1982

in chemicals and allied products and electrical and electronic equipment. A greater percentage of foreign patents in 1977 were highly cited in the fields of engines and turbines, aircraft and parts, professional and scientific instruments; and transportation equipment—in particular, motor vehicles, motorcycles, railroad equipment, and guided missiles and space vehicles. In 1971 a greater percentage of U.S. foreign-origin patents also were highly cited in most of these product fields, but by 1977 the percentage differences between U.S. domestic and foreign-origin patents had increased. In fact, in 1977 the actual number of highly cited patents was greater for foreign-origin patents in each of these fields except railroad equipment, guided missiles, and professional and scientific equipment.

U.S. Patenting Abroad

Figure 1-9 shows that U.S. patenting activity in other countries as well as in the United States has decreased over the decade. From 1971 to 1981, U.S. patenting with Canada, Japan, and the European Economic Community declined about 40 percent.[69] Almost 60 percent of the decrease in U.S. patenting activity abroad occurred in the United Kingdom and Canada. U.S. inventors have received a large portion of the patents granted to foreigners in many countries, but in 1981, the U.S. share of foreign patents granted was less than it was a decade earlier in each of the countries examined except Japan. (See appendix table 1-18.) Over the past 10 years, the U.S. proportion of foreign patents decreased from 45 percent to 32 percent in West Germany, from 41 percent to 37 percent in the United Kingdom, and from 32 percent to 28 percent in France. Some of the decrease in U.S. patenting in Canada may have been caused by restrictions imposed on foreign

Figure 1-9
Patents granted to U.S. inventors by selected countries



See appendix table 1-18

Science Indicators — 1982

[69]Comparable data for Italy are not available, and patents granted by France are not included because of wide fluctuations in patents granted to foreigners.

Table 1-5. Percent of highly cited[1] U.S. patents by nationality of the inventor, for selected product fields: 1971 and 1977

Product field	1971 U.S.	1971 Foreign	1977[2] U.S.	1977[2] Foreign
Food and kindred products	17	12	21	16
Textile mill products	11	11	13	13
Chemicals and allied products	11	9	11	10
Chemicals, except drugs and medicines	11	9	11	10
Drugs and medicines	12	15	17	16
Primary metals	12	15	23	16
Fabricated metal products	12	11	21	17
Machinery except electrical	11	9	20	20
Engines and turbines	11	14	9	17
Office computing and accounting machines	13	8	13	11
Electrical and electronic machinery, equipment and supplies	15	12	15	13
Electrical equipment, except communication equipment	12	9	13	11
Communication equipment and electronic components	12	10	17	15
Transportation equipment	11	12	17	24
Motor vehicle and motor vehicle equipment	11	12	10	18
Guided missiles and space vehicles and parts	11	10	14	20
Railroad equipment	12	17	15	17
Motorcycles, bicycles, and parts	13	17	15	20
Ordnance, except missiles	12	16	13	3
Aircraft and parts	9	14	10	17
Professional and scientific instruments	14	10	13	14

[1] Patents are ranked within each product field by the number of citations they receive from subsequent U.S. patents granted in the period 1971–80. A citation threshold was determined separately for each product field and time period. Only those patents above these thresholds were considered "highly cited."

[2] Patents appearing in the most recent years would not have time to accumulate citations. Therefore, the most recent year for which full patent citation data are feasible is 1977.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

companies, but the U.S. share of foreign patents (although still high) declined from 65 percent in 1971 to 59 percent in 1981. U.S. inventors were responsible for about half of all foreign-origin patents in Japan. (This compares with Japanese inventors accounting for 32 percent of foreign-origin patents in the United States.) These trends indicate that U.S. inventors have reduced their foreign patenting to a greater extent than have inventors in other nations.

The U.S. changes in foreign patenting may be due to many of the same factors which affect domestic patenting: a decrease in U.S. inventive activity, an increased propensity to use trade secrets rather than patents to protect proprietary information, or lower expectations of economic returns. The Patent Cooperation Treaty, which went into operation in June 1978, might result in an increase in U.S. patenting activity in Europe as a whole, since it simplified the filing of patent applications on the same invention in different countries. The total effect of this treaty is yet to be seen.

Another possible factor affecting U.S. patent trends abroad is the spread of multinational corporations (MNC's). U.S.-based multinational companies may opt to patent first in the United States or have their subsidiaries patent abroad. In the latter case, the U.S. subsidiary would assume the nationality of the host country and the patent would therefore be registered as a domestic patent of that country. There has been an increase in the amount of R&D performed abroad by U.S. companies and in the manufacture of new products abroad by R&D-intensive U.S. subsidiaries. (See the next section on technology transfer and particularly table 1-7 and appendix table 1-36.)[70] U.S. subsidiaries may be patenting products of their R&D in the host country. To what extent a subsidiary is controlled by its parent company, the extent of national identity that can be ascribed to an MNC and its subsidiaries, and the economic impacts associated with MNC operations are all difficult to determine.

Patenting by multinational corporations is also a factor in U.S.-originated patents. Prior to 1973, foreign direct investment in the United States was growing at an average rate of around 6 percent, but since then has been increasing at an average annual rate of about 20 percent. With this increase in foreign investment, more U.S. technology may be controlled by foreign companies.

[70] The decision of a firm on how best to exploit a patent depends on the size of the foreign market and tariffs. See ref. 48, pp. 21-28.

Appendix table 1-19 presents information on the U.S. patenting activities of the five European and five Japanese corporations with the greatest number of patents granted in the United States during the period 1969-1980.[71] This is a select sample of MNC's and therefore is not necessarily representative of all MNC's. Nonetheless, these companies do represent some of the largest and most active MNC's in terms of U.S. patenting. The top five of these foreign multinational corporations (FMNC's) in terms of world sales are also within the top six FMNC's in terms of U.S. patenting. The FMNC patents discussed here include both those patents assigned to wholly owned subsidiaries and those patents assigned to affiliates of which the parent controls more than 50 percent. Together, the 10 FMNC's own or control on the average 4.7 percent of all U.S. patents granted each year. This is quite a large percentage given that these firms represent less than 0.3 percent of the 65,000 companies assigned patents in the United States since 1969. About one out of eight U.S. foreign-origin patents is either owned or controlled by these 10 FMNC's, which indicates a concentration of foreign inventiveness.

Productivity and Technological Advances

It is difficult to quantify the exact and unique contribution of research and development to productivity and economic growth. Numerous conceptual and empirical problems are involved, such as insufficient understanding of the process of how research is transformed into technological innovation and its subsequent impact on the economy. Current productivity measures and GNP accounting procedures do not adequately reflect some factors that are direct beneficiaries of R&D efforts, especially qualitative improvements such as improved human health. Measured productivity growth also may seriously understate the contribution of a technological advance which leads to an improved quality or a broader range of goods or services.[72]

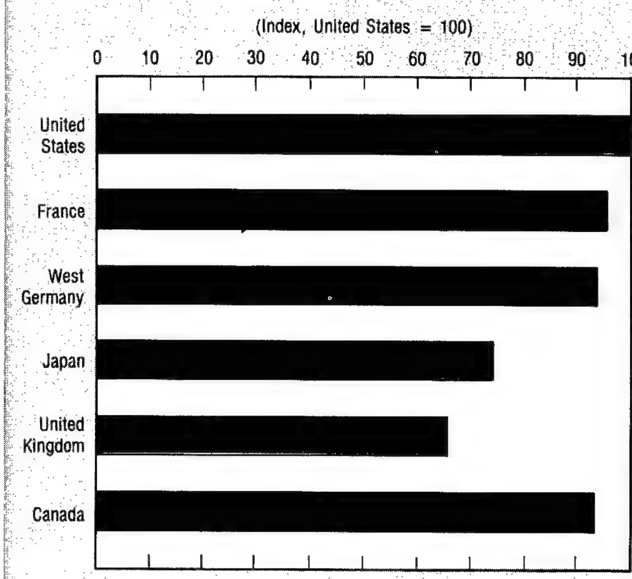
Although it is difficult to quantify the exact contribution, it is generally agreed that investment in research and development and in technological innovation has a positive effect on productivity and economic growth. Studies that have examined the impact of R&D at various levels—including specific innovations, firms, industries, and the whole economy—confirm that the contribution of R&D is important and indicate that the rate of return on R&D investment is as high as or higher than the return on other types of investment.[73] At the same time, the state of the economy also impacts on R&D. A slowdown in economic growth, as well as lower profits, tends to discourage long-term investments such as those in R&D, while high productivity helps to increase profits and fight inflation.[74]

The United States still maintains the highest overall productivity level in the world as figure 1-10 shows. While countries such as Canada, France, and West Germany have productivity levels close to that of the United States, Japan's productivity level is 25 percent lower. However, the U.S. advantage in productivity is being reduced. A decade ago, Japan's productivity level was almost 45 percent below that of the United States, and those of France and West Germany were about 25 percent lower.

Productivity is commonly defined as output per worker hour. This measure not only reflects the labor input, but also includes the contributions of technological advancement, capital investment, level of output, capacity utilization, energy use, and managerial skills.[75]

Figure 1-11 shows that over the past decade, the United States has experienced slower productivity growth than almost any other industrialized country (Canada's productivity growth was equally slow). From 1975 to 1982, productivity in manufacturing industries in the United States grew 11 percent, while productivity rose more than four times faster in Japan, more than three times faster in France, and more than twice as fast in both West Germany and the United Kingdom.

Figure 1-10
Real gross domestic product per employed person for selected countries compared with the United States: 1982



[1]Output based on international price weights to enable comparable cross-country comparison.

See appendix table 1-20.

Science Indicators — 1982

[71]The following information is from a special study by the Office of Technology Assessment and Forecast. See ref. 47, pp. 35-46.

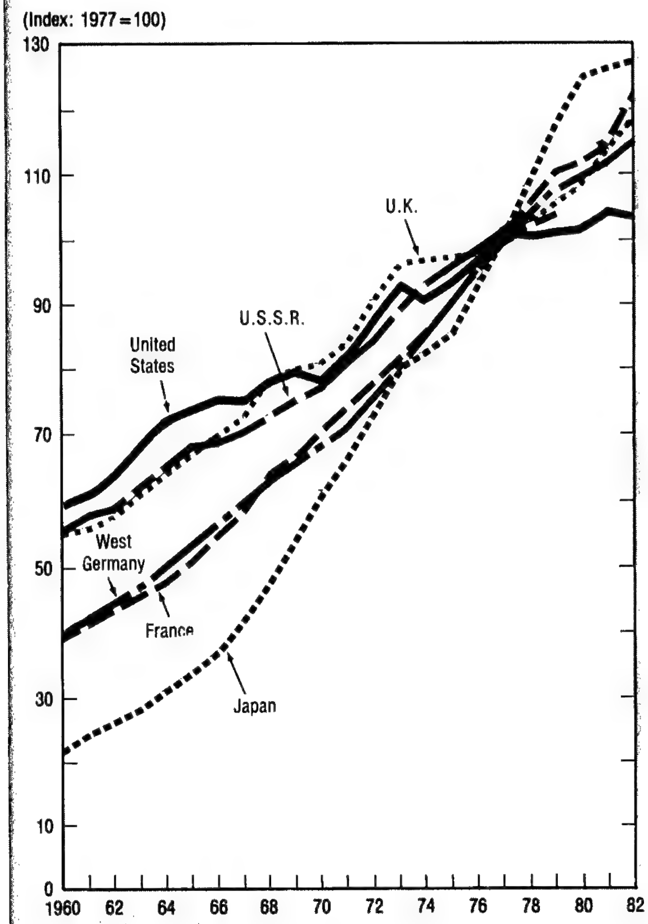
[72]A recent study which measured the impact of R&D on commercial air transportation circumvented some of these problems (in this specific area only) by comparing savings due to R&D expenditures with the cash flow returns from alternative investments and by comparing the costs of operating a "phantom fleet" of older technology aircraft with the costs of operating the actual fleet. The gains in domestic airline productivity in one year alone (1976) were found to be sufficient to pay nearly twice the costs of all the aeronautical R&D performed in the United States from 1923 to 1976. See ref. 22.

[73]Economists disagree about the precise extent of its contribution when examining the economy as a whole, in part because of the many factors involved and their interrelationship (e.g., R&D and capital investment). For instance, John Kendrick, using total factor productivity, calculates higher estimates of the contribution of organized R&D than does Zvi Griliches or Edward Denison. See refs. 110, 111, 112, 113, 114, 115, and 7.

[74]See refs. 9 and 4.

[75]See ref. 10, p. 2.

Figure 1-11
Relative change in productivity[1] in manufacturing industries for selected countries



[1]Output per worker hour.
NOTE: Estimates are shown for latest year.
See appendix table 1-21. Science Indicators — 1982

The slowdown in U.S. productivity growth since 1973 has undoubtedly been affected by many factors; one economist who carefully examined the U.S. productivity slowdown found that no one factor was the major cause,[76] while others have stressed the importance of R&D and high rates of investment in plant and equipment in encouraging economic growth and have concluded that low investment rates have been a major source of the relatively poor U.S. productivity growth performance.[77]

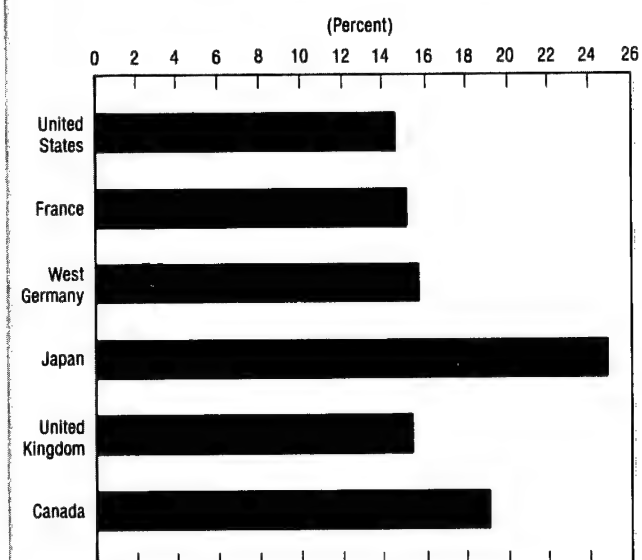
Unless R&D results are utilized, they cannot effectively influence economic growth. New capital investments often embody new technologies and R&D advances and so are presented here as an indication of the application of new technology.[78] Over the past decade, the United States has spent proportionately less on capital investment than the five other major industrial countries examined. (See figure 1-12.) Nonresidential capital investment as a percent of GNP was 14.6 percent in the United States during the period 1980-1981. In comparison, the Japanese capital investment rate was almost twice that (24.8 percent).

Replacement of capital equipment is particularly important for manufacturing industries if they want to utilize the latest technological developments and maintain their competitiveness. Age of equipment is an indicator of obsolescence, with a 10-year age period frequently used as a measure of machine utility. The percentage of machine tools under 10 years old as of 1978 is presented below for several countries and shows that the U.S. proportion of newer machine tools was one of the smallest of any leading industrialized nation:[79]

United States	31 percent
West Germany	37 percent
France	37 percent
United Kingdom	39 percent
Italy	42 percent
Canada	47 percent
Japan	60 percent

What has sometimes been referred to as the electronic information revolution is rapidly changing the nature of office and factory equipment and makes investment in new technological advances increasingly important if an industry or firm is to remain competitive. The Japanese have coined the word "mechatronics," which signifies

Figure 1-12
Capital investment, excluding residential construction, as a percent of output for selected countries[1]: 1980-81 period



[1]Fixed investments at market price as a percent of output at factor cost, in current dollar prices.
See appendix table 1-22. Science Indicators — 1982

[76]See ref. 114. Some have blamed modern U.S. management principles for the sluggish U.S. economic performance. See ref. 116, pp. 67-77. For comparison, see ref. 117, pp. 40-42.
[77]See ref. 113, pp. 122-147, and refs. 12, 13, and 14.
[78]See ref. 8, pp. 1054-1055.

[79]See ref. 15, p. 121.

the application of electronics technology to mechanical engineering.[80]

There are various aspects of factory automation, and some of the major components are: computer-aided design (CAD) systems, numerically controlled machine tools, robots, and computerized information systems. These components will be increasingly interconnected and integrated in the future. All of the above technologies are under development and are currently being used to increase productivity.

A recent report[81] on computer-aided manufacturing (CAM) in Japan, Western Europe, and Eastern Europe found that robotics is the most rapidly developing system component of computer-based automation in all three regions, and that most of the governments surveyed were investing heavily in national CAM projects. The diffusion and adoption of electronic machinery has been rapid. Table 1-6 shows the production of numerically controlled machine tools, which are automated devices that can fabricate components, and transport and assemble them following computerized instructions. The United States had produced the greatest number of units through 1976, but by 1979, Japan had surpassed the U.S. production by almost a factor of 2.

Although robots have been a subject of fascination for many years, the robot is currently the subject of intensified interest and is seen as a widely applicable tool. Robots represent only one aspect of the general trend toward computerized automation throughout industry which also includes computer-aided design and computer-aided manufacturing (CAD-CAM) and numerically controlled machine tools and computerized information systems.

The Robot Institute of America defines a robot as a reprogramable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programed motions for the performance of a variety of tasks. The Japanese concept is broader and includes manual manipulators and fixed sequence machines.[82] Many of the Japanese robots are of this simple or first generation type. This difference in definitions can be a source of confusion in quantitative analyses, but U.S. definitions are used here.

Table 1-6. Production of numerically controlled machine tools: 1973–79
(number of units)

Year	United States	Japan	France
1973	2,865	2,765	NA
1974	4,210	3,040	535
1975	4,136	2,182	612
1976	3,856	3,286	576
1977	4,482	5,436	574
1978	5,688	7,336	867
1979	7,174	13,514	1,068

NA = not availble.

SOURCE: David Beckler, "The Electronic Revolution in the Workplace," *The OECD Observer* (March 1982), p. 19.

Science Indicators—1982

[80]See ref. 19, p. 7.
[81]See ref. 118.
[82]See ref. 15, p. 28.

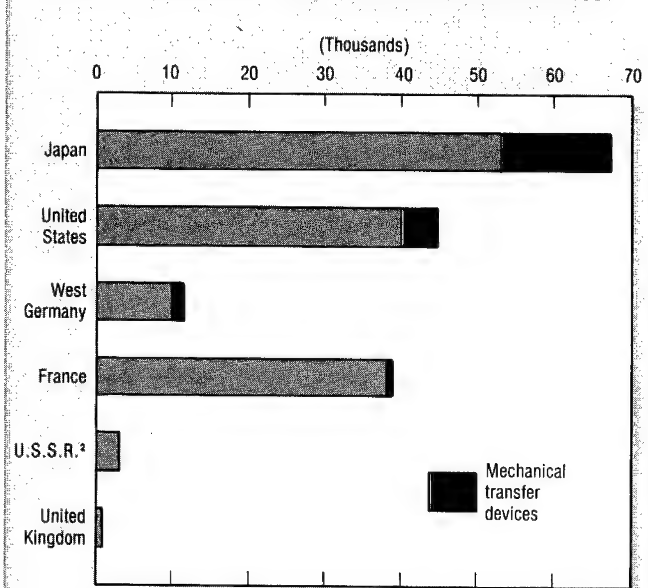
Much of the original research in robotics was done in the United States, and many believe this country remains the leader in robotics research.[83] However, robotics research in Europe and Japan is treated as crucial to national economic development and university robotics research is heavily subsidized by their respective Governments.[84]

While the United States has been a major contributor to basic research on robotics, Japan is clearly the current leader in robot production and utilization. Figure 1-13 shows the number of installed robots in selected countries throughout the world. Japan is responsible for over half and the United States for almost one-fifth of all of the robots excluding mechanical transfer devices. In comparison, West Germany accounted for 5 percent and the United Kingdom and France almost 3 percent of all such robots in 1981. If mechanical transfer devices are included in the comparison, Japan has almost 40 percent of the world's installed robots while the United States has one-fourth and France has one-fifth of the world's robot population.[85]

In terms of future economic competitiveness, the importance of robots is twofold—both in developing and selling the technology itself and in utilizing robots to produce higher quality goods at lower prices.

In summary, the United States still maintains the highest economy-wide levels of productivity, but other countries have been increasing their productivity at faster rates. Many factors affect economic growth and productivity, including R&D investments, capital investments, and development

Figure 1-13
Number of robots[1] installed in selected countries: 1981



[1]Includes mechanical transfer devices (pick and place) except for the United Kingdom.
[2]Information on types of robots not available.
See appendix table 1-23.

Science Indicators — 1982

[83]See ref. 16, p. 24, and ref. 15, p. 17. The idea of industrial robots is considered to have started by George C. Devol, an American, in 1954.
[84]See ref. 17, pp. 75-76.
[85]See ref. 18, p. 2.

and utilization of new technological advances. Although the United States has one of the highest levels of total R&D investment, other countries have higher civilian R&D and capital investment rates. The United States has taken the lead in many advanced technologies, but in many cases that lead has decreased. Other countries—particularly Japan—are emerging as leaders in specific areas or have surpassed the United States in the production and use of some advanced technologies.

INTERNATIONAL TECHNOLOGY AND TRADE FLOWS

Over the past two decades, the U.S. trade performance has benefited from trade in R&D-intensive products. However, as international technological and economic competition has increased, concern has heightened over the international transfer of industrial technology and the impacts of this diffusion upon U.S.-based production and industrial products.[86] To shed light on technology trade and transfer issues, this section deals with the extent and direction of technology flows and channels of transfer insofar as they have been measured.

The proponents of increased restrictions on technology transfer claim that the overall impact of such transfers on the United States is negative and results in lost jobs and market opportunities.[87] The transfer of some technologies to the Soviet Union, China, and Eastern Europe also is thought to be detrimental to the U.S. national security and strategic position.[88] Those favoring less restricted transfer of technology and trade argue that R&D-intensive products are an important component of U.S. trade, that it is impossible to restrict the flow of information and technology, and that if the United States does not provide requested services and products, other countries will gladly do so and benefit from the sales.[89]

At present, the magnitude and significance of technology transfer cannot be accurately assessed. Strictly defined, a technology has been transferred only if effectively applied by the recipient.[90] However, because of the difficulties in determining the actual utilization of the technology, measures of what may be more properly termed technology and information flows will sometimes be presented as indicators of technology transfer. While all the indicators in the following discussion have limitations as measures of technology transfer, considered together they can present a picture of what is occurring in U.S. technology trade and transfer transactions abroad.

Technological products and information can be transferred or transmitted in a variety of ways. The unobstructed exchange of scientific and technical literature is one of the main channels of information transfer. Exchange of technological know-how through personal contacts—including training of personnel, permanent or temporary immigration and emigration of scientists and engineers, and attendance at technical meetings and conferences—is another important means of transfer.[91] Embodied technology is exchanged in the form of exported or imported goods and services which can be used as intermediate products or imitated through means of reverse engineering. A holder of a patent may license the use of this proprietary information to another party, or a firm may make a direct capital investment in another country and transfer technology to its subsidiary. This section of the report deals primarily with technology flows related to foreign direct investment, licensing agreements, and R&D-intensive trade, since these are the major channels for the transfer of U.S. industrial technology that have been measured.

R&D-Intensive Trade

The United States was the dominant world leader in industrial technology for many years after World War II. However, by the 1960's, other countries had displaced the United States in many products. The composition of American goods and services competitive on the world market shifted toward capital goods and services embodying significant investments in research and development. The United States has a very high concentration of its manufactured exports in R&D-intensive areas.[92]

Although technology plays an important role in U.S. trade,[93] increased R&D expenditures by U.S. industries will not guarantee an improved trade performance. In fact, because industries are linked economically, increased R&D in one industry could improve the competitiveness of that industry at the expense of another, either through direct competition or by diverting capital and labor and increasing the price of certain common productive factors. However, increased R&D in one industry often will have positive effects on other industries in the form of technically superior and more cost-effective inputs[94] as well as final product improvements.

The U.S. trade in manufacturing products is examined here by products differentiated by levels of R&D investment. An industry-based definition is used in which R&D-intensive product fields are defined as those associated with industries with above average R&D funding and employment—that is, with an average of 25 or more scientists and engineers engaged in R&D per 1,000 employees and total R&D funding amounting to at least 3.5 percent of net sales. The four product groups that meet these criteria are chemicals and allied products, machinery (electrical and nonelectrical), aircraft and missiles, and professional and scientific instruments.[95] Not all products manufactured by an R&D-intensive industry are necessarily R&D-intensive products, and industries can perform R&D in several different product fields. However, the fields considered here as R&D-intensive are among the top in applied R&D expenditures, and from 81 percent to 98 percent of all U.S. research and development performed in these product fields is conducted by the industries that manufacture these products.[96]

[86] See refs. 55, 95, and 96.
[87] See refs. 97, 98, and 99.
[88] Several thorough studies are available on the topic of technology transfer to communist countries. See refs. 100, 101, 102, 54, and 123.
[89] See refs. 103, 104, and 98.
[90] See ref. 105.

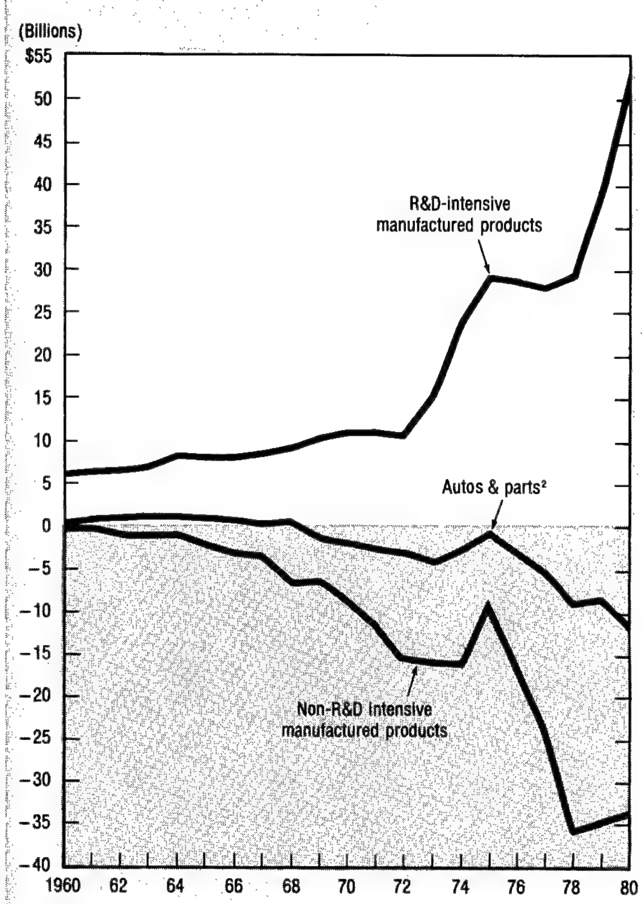
[91] See the section of the chapter dealing with international science and technology cooperation.
[92] See ref. 56, p. 14.
[93] See refs. 57 and 58.
[94] See ref. 59, pp. 24-26.
[95] See ref. 60, pp. 23, 35.
[96] See ref. 61, pp. 50-51.

Alternative definitions have been used to define R&D-intensive industries or products, and they are sometimes referred to as technology-intensive or high technology products/industries. While some categories are more inclusive or less inclusive than those identified here, the trends are similar, regardless of which definitions are employed.[97]

The trade balance in R&D-intensive manufactured products has been positive and growing over the past decade as shown in figure 1-14. It increased dramatically since 1972, reaching $52.4 billion in 1980. This strong performance has helped the overall U.S. merchandise trade balance, which has been negative since the mid-1970's (largely due to increased petroleum prices), and registered a deficit of $24.2 billion in 1980. Non-R&D-intensive manufactured products have had a poor trade performance over the past 10 years. Between 1970 and 1978, the balance dropped over 300 percent, but has shown some recovery since then, reaching a deficit of $33.5 billion in 1980. Much of this imbalance has been due to increases in imports of iron and steel mill products and automobiles. The motor vehicles and parts industry initially registered a positive balance, but since 1967 has shown a deficit. There was some recovery between 1973 and 1975, but since then the deficit in automobiles has grown to $10.9 billion.[98]

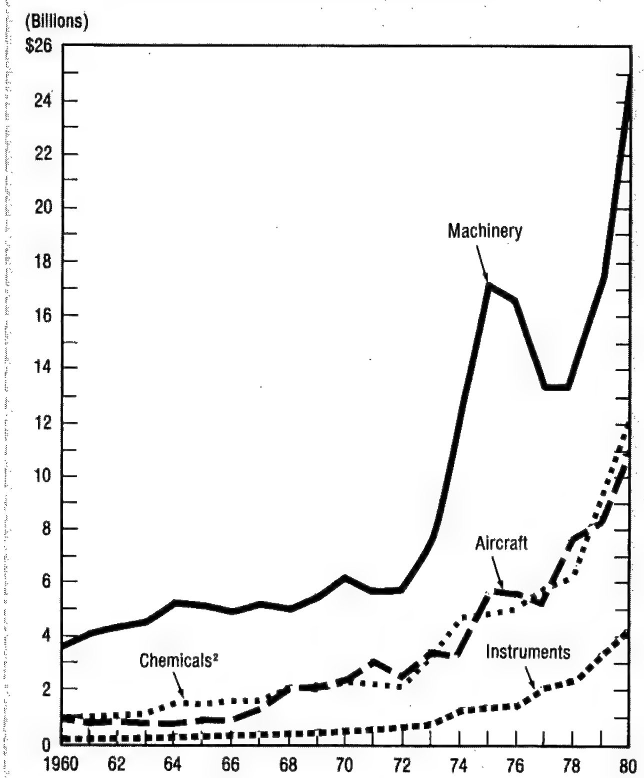
Figure 1-15 shows that machinery (both electrical and nonelectrical which includes computers, consumer electronics, etc.) has been the major product group responsible for the trade surplus in R&D-intensive goods; machinery

Figure 1-14
U.S. trade balance[1] in R&D intensive and non-R&D-intensive manufactured product groups



[1]Exports less imports.
[2]Included in the non-R&D intensive manufactured product balance because it only became an R&D-intensive industry in 1980.
See appendix tables 1-24 and 1-26. Science Indicators — 1982

Figure 1-15
U.S. trade balance[1] in selected product groups



[1]Exports less imports.
Includes drugs and other allied products.
NOTE: After 1977, the Commerce Department made revisions in the product group classifications which somewhat affected the balances of these product groups. The overall R&D-intensive balance on figure 1-14 was unaffected.
See appendix table 1-26. Science Indicators — 1982

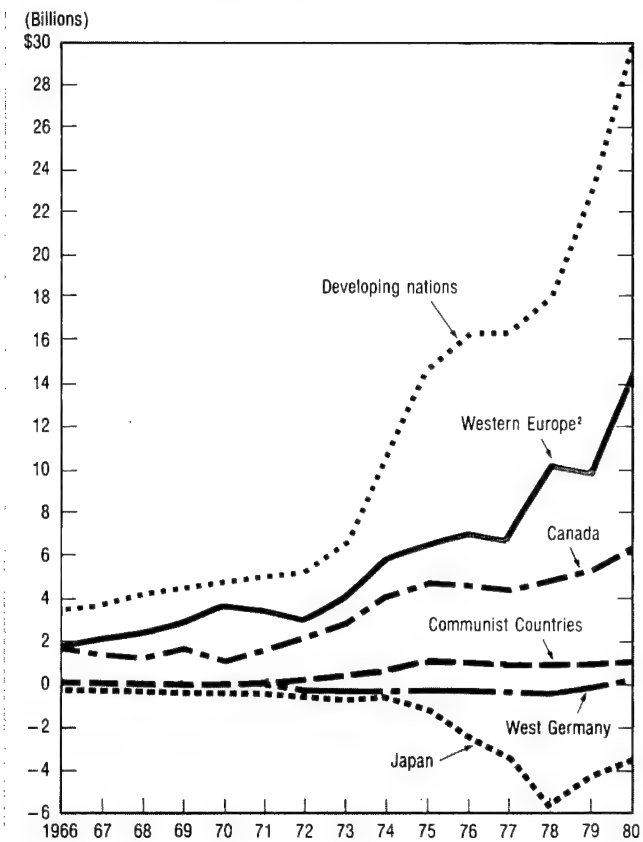
[97]See refs. 62, 63, and 64 for a discussion of the various categories. A recent study which presents another definition of technology-intensity based on total expenditures for applied research and development concludes that the U.S. competitive position in "high technology" products is deteriorating. See ref. 124. There is also evidence of this decrease in appendix tables 1-28 and 1-29.

[98]Motor vehicles and parts are shown as a separate product group for several reasons including the importance of this industry to the U.S. economy and the large U.S. foreign investment abroad by this industry which is germane to the question of technology transfer.

products are responsible for almost half of the balance and constitute almost 60 percent of the R&D-intensive exports. Between 1978 and 1980, the positive balance in machinery increased 87 percent. Most of this growth can be attributed to large increases in exports of electronic computers, agricultural tractors and parts, internal combustion engines, and mining and well-drilling machines.[99] The trade surplus in scientific and professional instruments has been on the rise since 1972, reaching $4.3 billion in 1980—three times its level in the mid-1970's.

The United States has a positive trade balance in R&D-intensive manufactured products with all its major trading partners except Japan. Figure 1-16 shows that the surplus is particularly high with developing countries, indicating that the U.S. is transferring large amounts of embodied technology to these countries. Developing countries accounted for over 40 percent of all U.S. exports, with machinery and chemicals representing the largest product groups sold to these countries.

Figure 1-16
U.S. trade balance[1] with selected nations for R&D-intensive manufactured products



[1]Exports less imports.
[2]Includes West Germany.
See appendix table 1-27.

Science Indicators—1982

The R&D-intensive trade balance with Western Europe as a whole is positive and reached $14.6 billion in 1980. Over 30 percent of all R&D-intensive exports were to Western Europe. Trade with West Germany in these products has shown deficits in chemicals and machinery products but the overall R&D-intensive trade balance was positive in 1980.

The negative trade balance with Japan began to worsen markedly in 1974. By 1978, the trade deficit in R&D-intensive products was $5.7 billion—10 times what it had been in 1974. The deficit subsequently has lessened somewhat, and was $3.6 billion in 1980.

The United States is the principal exporter to Japan, with chemicals and machinery representing 30 percent of Japanese imports of U.S. goods.[100] However, Japanese imports from the U.S. have not grown as fast as Japanese exports to the United States in machinery, particularly telecommunications apparatus, consumer electronics and office machines. The United States has a positive trade balance with Japan in chemicals, aircraft, and professional and scientific instruments.

U.S. technological strength is being challenged in a number of areas by foreign firms. A recent study of U.S. competitiveness in high technology industries concluded that the economic health of the Nation depends on high technology, and that a weakened position in technology adversely affects national security.[101]

Although the United States still has the largest share of world trade in R&D-intensive products, that share has declined as is evidenced in figure 1-17. In the 1970's, the United States was responsible for 23 percent of trade in these products,[102] but by 1980, the U.S. share was only 20 percent. Japan increased its export share from 10 percent in 1970 to almost 15 percent in 1980. The export shares of France and West Germany remained relatively stable. In 1980, the West German share of world exports in R&D-intensive products was roughly equal to that of the United States.

A recent study of U.S. trade competitiveness of these products provided further evidence that since the mid-1970's the import share of U.S. consumption has risen.[103] Appendix table 1-29 shows that from 1970 to 1980, U.S. market shares declined in aircraft (12.9 percentage points), electronic components (12.2 percentage points), and jet engines (8.4 percentage points). U.S. market shares in computers rose 4 percentage points, and consumer electronics held its own and increased slightly.[104] Japan achieved large gains and France had small gains in market shares in many of the areas in which the U.S. experienced declines.

Concern has also heightened over national security implications of technology transfer to communist countries.[105] The fear is not only that technology which is of direct military application may be transferred, but that high technology trade may help to improve civilian industries which can serve as an S/T infrastructure for future military capabilities. In light of these concerns, several different

[99]Determined from data in ref. 50, pp. 7-11, and ref. 51, pp. 6-16. See also ref. 49 for a discussion of semi-conductor trade.

[100]See ref. 52, pp. 82-88.
[101]See ref. 55.
[102]This includes automobiles.
[103]See ref. 124, pp. 22-23.
[104]See ref. 55, pp. 28-29.
[105]See ref. 53.

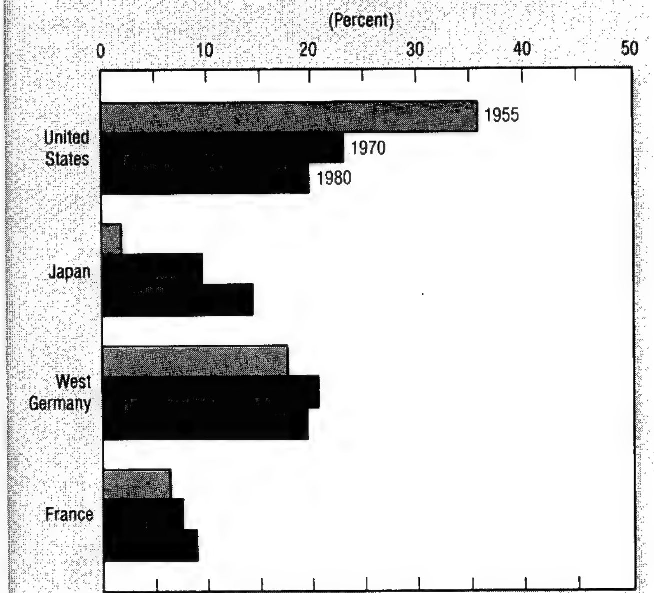


Figure 1-17
Comparative changes in world export shares of R&D-intensive products[1]

[1]Includes automobiles as well as the product groups in figure 1-13.
See appendix table 1-28. Science Indicators—1982

hearings and panels have been called to deal with the issues of technology transfer, national security, and effects that increased controls might have on the scientific community.[106]

U.S. exports of R&D-intensive manufactured products to communist countries in Europe and Asia, while relatively small, increased rapidly from 1968 to 1975 and reached a level of $1.3 billion in 1980. Of course, the dollar amount of the transfer does not necessarily equate with the value to the recipient, particularly in this case, but it does provide an indication that a significant amount of embodied technology is being transferred to communist countries via trade in R&D-intensive products. Exports to these countries represent only 1 percent of total U.S. exports in R&D-intensive manufactured goods. The largest portion of these exports (45 percent) are in machinery. Chemicals and allied products constitute almost 36 percent of the R&D-intensive exports.

Appendix table 1-30 puts U.S. trade with these countries in perspective by comparing Soviet imports of U.S. goods in select product groups with those of other industrialized countries. It demonstrates that Soviet imports of high-technology products from the United States are smaller than those from West Germany, France, or Japan (and much smaller than their combined exports). One obvious conclusion that can be drawn from this table is that while U.S. exports to communist countries may be small, our allies have been exporting a great deal more of these products to the Soviets than has the United States and may be a comparable source of similar products.

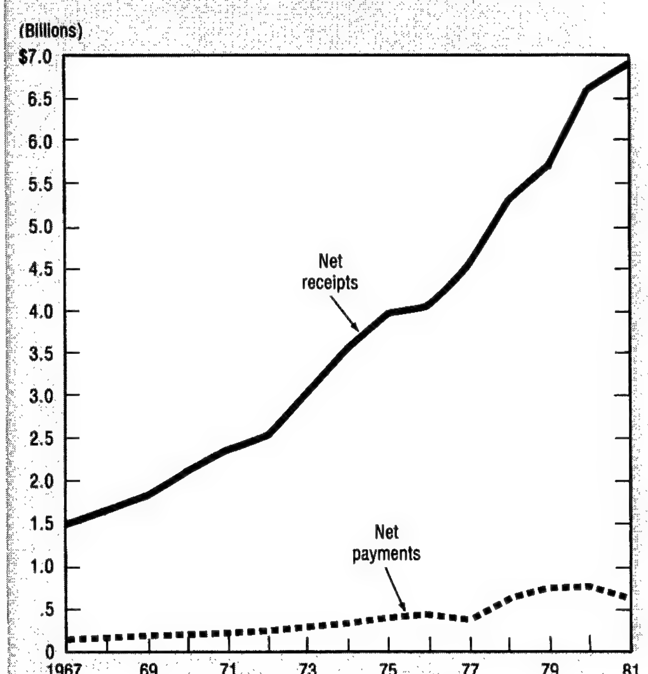
Royalties and Fees

Royalties are payments for the use of copyrights or trademarks; licensing fees are charges for the use of a patent or industrial process. Data on international transactions in royalties and fees are frequently used as indicators of the technology transfer. Data on receipts and payments are often disaggregated between those transactions associated with direct investment and those which are between independent or unaffiliated organizations. Examples of direct investment-related transactions are those between an American company and its subsidiary abroad, or conversely, payments to and receipts from a foreign parent by a U.S. affiliate. The data presented here do not include charges for film and tape rentals. This exclusion improves the value of royalties and fees data as technology flow indicators.

U.S. transactions on royalties and fees are presented in figure 1-18 which demonstrates that in dollar terms the United States sells about nine times more technical know-how than it buys through these channels. U.S. receipts have steadily increased—more than 190 percent over the past 10 years and more than 70 percent since the mid-1970's. In 1981 U.S. receipts for royalties and fees totaled $6.9 billion.

Examination of other industrialized countries' technological balance of payments for royalties and fees shows that the United States stands out as a net exporter of technology.

Figure 1-18
U.S. International transactions in royalties and fees



See appendix table 1-33. Science Indicators—1982

[106]For example, see ref. 71. The National Academy of Sciences and the National Academy of Engineering recently released a report by an 18-member panel which examined the issue of Government export controls on academic research, see ref. 123. A joint Department of Defense-University Forum has been established to try to come to some agreement which would balance academic principles with national security needs.

Appendix table 1-31 shows the ratios of receipts to payments (a ratio greater than 100 signifies a net exportation of technical know-how) and points out that through these channels, Japan, West Germany, and France have all been net importers of technology. In France and Japan, the receipts to payments ratios have steadily increased during the 1970's indicating a lessening dependence on imported technology. West Germany's ratio has remained fairly steady; it is a net importer in affiliated transactions and a net exporter in unaffiliated transactions.[107] In 1980, payments were over two times the receipts in West Germany and France and about four times greater in Japan.

Japan is a net importer of technical information, particularly from North America, but exports such information as well. Japan is transferring its technology largely (over 40 percent) to countries in the region of Southeast Asia. However, among individual countries, the largest purchasers of Japanese technical information are the United States and the People's Republic of China, each representing about 14 percent of all Japanese receipts from royalties and fees.[108]

About 80 percent of all U.S. royalties and fees receipts come from U.S. subsidiaries abroad. (See appendix tables 1-33 and 1-34.) This concentration in technology transfers related to direct investment suggests that U.S. companies prefer to make transfers to affiliated companies where it is possible to have more control over the use of their technologies, thereby protecting their competitive edge.

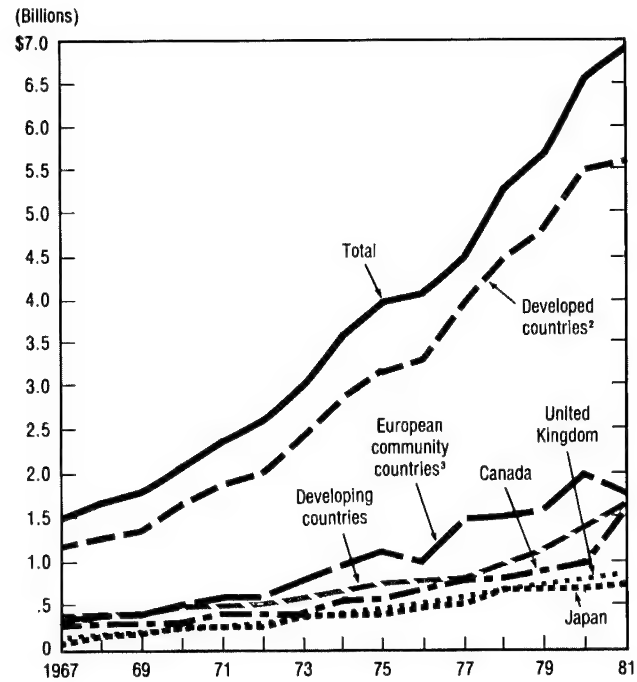
Appendix table 1-32 shows that almost 70 percent of all the U.S. direct investment-related transactions were in manufacturing industries. One-fourth of these were in the chemicals industries, and 28 percent were in machinery (including electrical machinery). Almost one-fifth of all transfers of technical know-how in the chemical industry were to subsidiaries in the United Kingdom, and 15 percent of all nonelectrical machinery (including office machines) transactions were with U.S. affiliates in Japan.

Over four-fifths of the purchasers of U.S. technical know-how are from developed nations (see figure 1-19), most of them in Europe. Developing countries received about 20 percent of all these technology transfers (predominately going to U.S. subsidiaries).

Differences may occur in the economic impacts of unaffiliated licensing agreements. There is likely to be less control over the utilization and dissemination of technology transferred to an unaffiliated firm than to a subsidiary. In the past, Japan has purchased U.S. technology primarily through unaffiliated sources; in 1971, for example, over 70 percent of the U.S. transactions were with independent Japanese firms. Since liberalization of Japanese laws concerning foreign direct investment in the late 1960's and early 1970's,[109] an increase in technology transfers between foreign companies and their Japanese subsidiaries has occurred. In 1981, U.S. receipts of royalties and fees from Japan were about equally divided between affiliated and unaffiliated sources. However, the Japanese Government still exercises a great deal of control over licensing agreements and can cancel or modify a transaction if it is seen as adverse to the domestic industries involved.[110]

[107]See ref. 65, p. 13.
[108]See ref. 68, pp. 124-127.
[109]See ref. 70.
[110]See ref. 65, pp. 26-28.

Figure 1-19
U.S. receipts of royalties and fees from selected nations



¹Represents net receipts of payments by U.S. firms from both their foreign affiliates and unaffiliated organizations for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management, etc. Excludes firm rentals which are included in the royalties and fees data in the international transaction tables of the *Survey of Current Business*.

²Developed countries included here are Western Europe, Canada, Japan, Australia, New Zealand, and the Republic of South Africa.

³Original six members only.

See appendix table 1-33. Science Indicators—1982

Royalties and fees data are only rough and partial measures of international technology flows for a variety of reasons. These data are a partial measure because much technology passes across national borders through other channels. For example, trade in R&D-intensive products provides the opportunity to facilitate uses of new technology by reverse engineering such products or upgrading technical capabilities by integrating high technology products into domestic industrial processes. Some industrial technology transfers may not be paid for separately if they are part of a larger transaction or operation.

The charge for proprietary knowledge in direct investment-related transactions—which account for 80 percent of the total receipts in the United States—is likely to be influenced by corporate decisions in addition to a determination of the actual value of the technology concerned, for instance, tax considerations and interest in entering foreign markets.

Unaffiliated transfers may underrepresent the true value of the technology transferred because receipts and payments data do not reflect other means of augmenting the price of the technology, such as tie-in sales, agreements to purchase immediate goods from the licensing firms, or exchange of rights to other technologies or technical assistance.[111]

[111]See ref. 69.

Independent firms may also undervalue their proprietary knowledge to be competitive.

Several other limitations to the U.S. data should be mentioned. The royalties and fees data include payments for access to trademarks. These payments do not directly involve technology, but cannot be separately identified from the other payments. However, because trademark rights are usually tied to quality control restrictions on production processes, these rights are indirectly linked to technology. Trademark rights may also be another way of charging for the value of a firm's technical know-how.

Some limitations of the royalties and fees data discussed here tend to overestimate the value of the technology transferred, while others tend to underestimate the value; it is difficult to say where the balance lies. The data do clarify that the United States is a net exporter of technological information, and that the majority of technology transfer transactions are between parent companies and their affiliates. Further, many of the transfers seem to be in the machinery and chemicals and allied products industries. Examining other indicators of technology flows—all of which show that the United States is a net exporter of technological information and products—reinforces the basic trends represented by the royalties and fees data.

Direct Investment Abroad

Another method of transferring technology is by establishing overseas subsidiaries. Many corporations have become multinational to exploit a technological lead in other countries, or because foreign import restrictions make the establishment of overseas production facilities the only viable alternative for a foreign firm to introduce its product. Although it is difficult to determine precisely how much technology is transferred through direct investment activities abroad, multinational firms do transfer large amounts of technology in a variety of ways. These firms train technicians and managers, communicate information and capabilities to engineers and technicians, help client companies use their products more effectively, and assist suppliers in upgrading their technologies.[112]

The extent of direct investment abroad affects the amount and value of licensing agreements[113] and the amount of U.S. research and development performed abroad. The production of technology-intensive products abroad has also increased with the growth of U.S. foreign direct investment. Studies show there has been a marked speedup in the spread of foreign production of new products by U.S. subsidiaries. Appendix table 1-36 shows that R&D-intensive firms appeared to be moving the production of their new products abroad at a faster rate than firms with lower R&D intensities.

U.S. direct investment abroad in manufacturing industries has grown almost 50 percent in the last 5 years, reaching $92.5 billion in 1981. (See appendix table 1-37.) This amount is not a direct measure of technology transferred but is representative of the level of U.S. investment abroad and is indicative of the presence of a positive environment for the transfer of U.S. technology. Almost half of all U.S. direct investment in manufacturing occurs in the machinery (26 percent) and chemicals (22 percent) industries. Most of this investment (almost 80 percent) is in industrialized countries, particularly in Canada, France, and the United Kingdom.

U.S. R&D Performed Abroad. U.S. companies are performing an increasing amount of R&D abroad and in the process may be transferring technical know-how. Table 1-7 shows that since 1975, R&D conducted by U.S. subsidiaries has more than doubled and in 1981 totaled $3.2 billion; this is equal to 9 percent of total U.S. company funds. In 1979, R&D expenditures performed abroad increased 25 percent—the largest increase since 1975. However, between 1980 and 1981 the overall amount of R&D performed abroad dropped 25 percent, largely due to a decrease in the amount of transportation R&D conducted overseas. Even so, the largest increase in terms of R&D dollars spent abroad over the period 1975 to 1981 was in the transportation industry, followed by the chemicals and allied products and electrical equipment industries. In 1981, more than half of all U.S. research and development performed abroad was in the machinery, chemicals, and electrical equipment industries. The transportation industry alone was responsible for almost 30 percent of the total R&D performed by U.S. affiliates. Much of these expenditures are actually for development projects to tailor products to local needs and markets.

Foreign R&D Performed in the United States

Foreign direct investment (FDI) in the United States increased substantially in the 1970's. During 1973-1979, the United States attracted over 30 percent of the total new FDI activity compared with only 3 percent throughout most of the 1960's.[114] Research and development performed by foreign affiliates in the United States has grown along with the increased U.S. role as a host country to FDI. From 1974 to 1979, R&D expenditures by foreign subsidiaries in the United States increased by almost 90 percent, exceeding $1.5 billion. (See table 1-8.) This is more than half the amount of R&D performed abroad by U.S. companies. Almost 80 percent of all the foreign R&D was in manufacturing industries, and almost half was in chemicals and allied products.

Does foreign investment in the United States result in an outflow of U.S. technology? Foreign firms have on occasion purchased American companies and thereby gained access to U.S. technology, but studies[115] have concluded that, for the most part, foreign companies invest in the United States to take advantage of the large, politically unified, and stable market rather than merely to access U.S. technology. Many foreign pharmaceutical companies have laboratories in the United States to conduct tests to meet the Food and Drug Administration's regulations and standards. In order to compete successfully in the U.S. market, foreign firms usually introduce their most sophisticated technologies and new management techniques.[116]

[112]See ref. 69.

[113]The ratio of the former to the latter was a stable 5 to 6 percent during 1967-1981. See appendix tables 1-34 and 1-37.

[114]See ref. 65, p. 18.

[115]See ref. 65, pp. 17-19; ref. 66; and ref. 67.

[116]For example, electric and electronic equipment accounted for 20 percent of the number and 16 percent of the value of completed FDI transactions. Many of these transactions were with United Kingdom and Japanese companies. Leading Japanese semiconductor firms such as Nippon Electric, Hitachi, Toshiba, Fujitsu, and Rohn have built plants in the United States. See ref. 65, pp. 18-19.

Table 1-7. Company R & D performed abroad by foreign affiliates of U.S. domestic companies by selected industry: 1975 and 1981
(U.S. dollars in millions)

Industry	1975	1981	Percent increase
Total	$1,454	$3,157	117
Food and kindred products	23	66	187
Chemicals and allied products	269	651	142
Industrial and other chemicals	85	275	124
Drugs and medicines	184	376	104
Stone, clay and glass products	7	15	114
Primary metals	9	9	—
Fabricated metals	([1])	26[2]	NA
Machinery	331	585	77
Electrical equipment	245	455	86
Electronic components	7	47	571
Transportation	412	893	117
Motor vehicles and other transportation equipment	373	791[2]	112
Aircraft and missiles	39	102[2]	161
Professional and scientific instruments	49	101	106
Other manufacturing industries	105	147	40
Nonmanufacturing industries	4	12	200

[1] Included in the other manufacturing industries group.

[2] Estimated.

NA = not available.

SOURCE: National Science Foundation, *Research and Development in Industry, 1981*, forthcoming.

Science Indicators—1982

Table 1-8. R&D expenditures by U.S. affiliates of foreign companies: 1974 and 1979
(U.S. dollars in millions)

Industry of U.S. affiliate	Expenditures		Percent change
	1974	1979	
Total	$813	$1,533	89
Petroleum	111	234	111
Wholesale trade	78	53	-32
Manufacturing	574	1,192	108
Food and kindred products	NA	46	NA
Chemicals and allied products	NA	722	NA
Primary metal industries	NA	16	NA
Fabricated metal products	NA	31	NA
Nonelectrical machinery	NA	94	NA
Electrical and electronic equipment	NA	148	NA
Other manufacturing	NA	133	NA
Other industries	50	54	8

NA = not available.

NOTE: Detail may not add to totals because of rounding.

SOURCES: Department of Commerce, *Foreign Direct Investment in the United States, Vol. 1,* "Report of the Secretary of Commerce to the Congress," 1976, p. 54; Ned G. Howenstine, "Selected Data on the Operations of U.S. Affiliates of Foreign Companies, 1978 and 1979," *Survey of Current Business* (May 1981) p. 49.

Science Indicators—1982

Therefore, the United States probably receives a net technology benefit from foreign investment.

INTERNATIONAL SCIENTIFIC COOPERATION

While the United States remains strong in many areas of research, it is no longer the undisputed leader in every field.[117] Other countries have expanded and strengthened their science and technical capabilities as is evident from earlier sections of this chapter. Newly industrialized countries such as Brazil, Mexico, Israel, and South Korea have also significantly improved their capabilities in science and technology. This situation offers the possibility of expanded S/T cooperation.[118]

International scientific cooperation contributes to the advancement of world science and diffusion of knowledge. It can also lead to lower research costs, improved research results, improved relations between countries, and greater human understanding. The direct exchange of methods and experimental results (e.g., through international meetings and the conduct of collaborative research) can often act as a synergistic impetus to domestic scientific research by providing fresh outlooks and new perspectives. Despite these advantages, there are possible drawbacks to international scientific cooperation, including time delays due to increased organizational complexities and decreased ability to make independent decisions about the direction and goals of the research.

International cooperative science includes activities such as joint R&D projects and seminars or workshops, exchange of scientists, joint commissions for scientific and technical cooperation, and participation in international scientific organizations. This section presents indicators of international scientific cooperative activities and interactions in which the United States is involved.

There are various reasons to engage in and support international scientific cooperation. The exchange of ideas can be a fruitful stimulus to research.[119] Often a particular scientific phenomenon or problem which is of interest to scientists of many countries is the impetus for international scientific cooperation. An example of this type of project is the Global Atmospheric Research Program (GARP), which is one of the most comprehensive international efforts ever mounted. It entails international cooperation to explore the world's weather and climate through computer modeling, observational and experimental studies. Sometimes international cooperation focuses on a unique facility such as CERN (the European Council for Nuclear Research), the *Glomar Challenger*, the U.S. deep sea drilling ship, or National Astronomy Centers. These are also examples of how international cooperation can help to share the expenses of unique facilities. This can be beneficial to the United States, as in the case of the Lawrence Livermore neutron source facility. It cost $5 million to build in 1978, and only half the facility has been in use because of a shortage of operating funds. The facility is now in full operation after the Japanese Government agreed to provide $2 million a year for 5 years in return for access to the facility for Japanese scientists.[120]

International S/T cooperation can provide foreign solutions to domestic problems or can help attack problems that transcend national borders. The improvement of international political relations are sometimes a reason for undertaking international S/T cooperation.[121] The normalization of relations with the People's Republic of China (P.R.C.) has been assisted by the promise and fulfillment of scientific and technical cooperation. A protocol was signed in December 1980 with China[122] for cooperation in a broad variety of S/T fields. An example of projects of interest to both countries is the U.S.-P.R.C. Cooperative Earthquake Research Program which encompasses joint research activities on fundamental seismology, earthquake prediction, earthquake engineering, urban planning and design, and mitigation of societal hazards. On the other hand, significant scientific relations can deteriorate as a result of political situations as in the case of the Soviet Union and Poland.

U.S. international S/T interaction can be sponsored or performed by the Government, the private sector, academia, or individual scientists. A sample of Government-supported S/T interactions can be useful in identifying regional and field concentrations. A tabulation of National Science Foundation research awards for cooperative projects with foreign institutions or organizations[123] shows that collaborative efforts are most often with industrialized countries (40 percent), closely followed by developing countries (30 percent). Regional projects, or those with a geographical scope beyond individual countries, received 22 percent of the awards, and collaborative projects with scientists from socialist countries accounted for 9 percent of all awards. Almost one-fourth of all NSF awards with international implications are in the environmental sciences, over one-fifth are in the life sciences, and 16 percent are in the physical sciences.[124] Joint efforts have been made by the U.S. Government and scientific community to strengthen the S/T infrastructure of developing nations. For example, with the support of the Agency for International Development (AID), the Board on Science and Technology for International Development (BOSTID) has examined ways to apply science and technology to development problems. Through studies, overseas workshops, advisory teams, and research grants, problems in areas such as agriculture, environmental planning, energy, nutrition, and water supply and quality have been addressed in over 35 countries in Asia, Africa, and Latin America. Much of the private sector collaboration is in the form of trade, royalties and fees

[117]See ref. 6, pp. 52-53.

[118]For a more comprehensive statement by the National Science Board on the importance and challenge of international S/T cooperation, see ref. 126.

[119]The value of personal contact with scientists of other countries has been documented in interviews with approximately 50 senior scientists, administrators, and government officials in visits to 12 universities, 5 research institutes, and a number of foundations, international research organizations, and Government bureaus in Great Britain, Switzerland, West Germany, and France. See ref. 89, pp. 193-213.

[120]See ref. 90, p. 1.

[121]For an extensive discussion of how science and technology create both opportunities and problems in the achievement of goals, see refs. 92 and 93.

[122]See ref. 94.

[123]In 1980, NSF made a total of 567 such grants which represented about 5 percent of all NSF awards granted in that year.

[124]See ref. 91.

transactions, or other activities discussed in the previous section. For instance, the largest portion of U.S. exports of R&D-intensive products is with developing countries and U.S. transfer of technology to developing countries via license agreements increased 200 percent over the past decade. International academic science and technology interaction is discussed below.

International Cooperation in Academia

U.S. universities and colleges have long been involved in a variety of international S/T activities. One of academia's main contributions is the education of foreign students. Other contributions include cooperative R&D programs, assistance in establishing or improving educational and research capabilities, and developing curricula in areas of special interest to developing countries.[125]

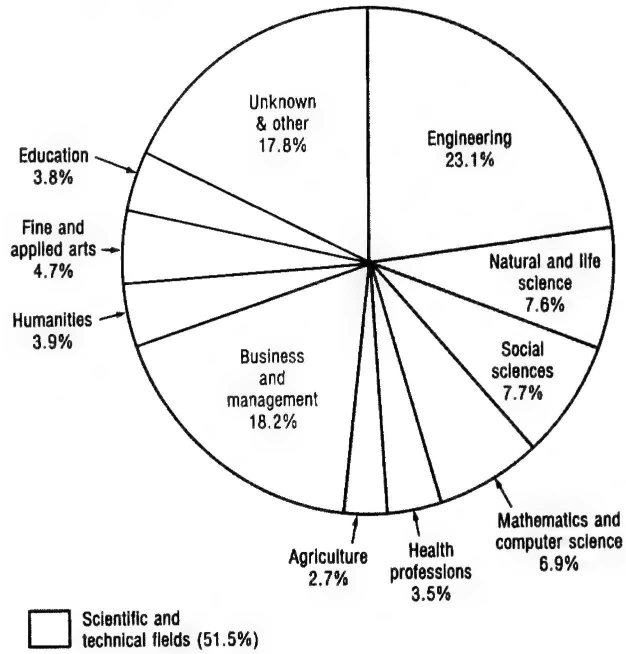
There were over 326,000 foreign students enrolled in U.S. universities and colleges in the academic year 1981-82. This was almost two times the number of foreign students studying in the United States in the mid-1970's. The number of foreign students in the higher education sector was only a very small portion of the total enrollment, however, representing only 2.6 percent of the total in 1981-82. Most of the foreign students are from developing countries—over 32 percent from Asia, 17 percent from Latin America, and 13 percent from Africa. OPEC nations have been training increased numbers of students in the United States; these nations represented 29 percent of all foreign students in 1981-82. Europeans represented only 9 percent of all foreign students. The leading six countries in terms of students enrolled in 1981-82 were Iran (15 percent), Taiwan and Nigeria (6 percent each), Canada (5 percent), and Japan and Venezuela (4 percent each).[126]

More than half (51.5 percent) of all foreign students are studying in scientific and technical fields and almost one-fourth of the foreign students are in engineering. (See figure 1-20.) In 1981-82 there were almost two times the number of foreign engineering students and two and one-half times the number of foreign students in mathematics and computer sciences than there were in the mid-1970's. (See appendix table 1-38.)

The past decade has seen an increasing number of foreign students coming to the United States for graduate training. Figure 1-21 shows the foreign proportion of doctoral degrees conferred by field. In 1981, about 22 percent of the doctoral degrees in science and engineering fields were awarded to foreign students. In engineering, foreign students constituted over half the graduating doctorates. Other fields with high proportions of foreign students receiving doctoral degrees were agriculture and forestry (38 percent) and mathematics (34 percent). Over one-fourth of all the doctorate recipients in computer sciences were foreign citizens.

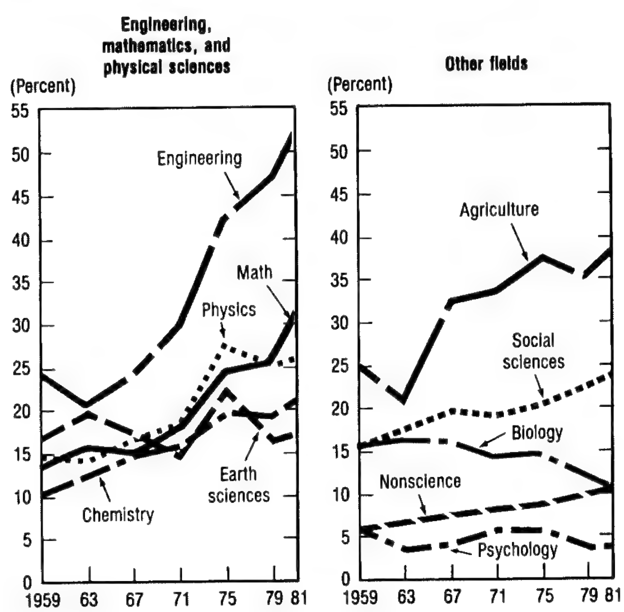
Foreign citizens with temporary visas received at least one out of five of the S/E doctorates awarded in 1981 in each of more than 50 subspecialties. The largest shares were in agricultural engineering (66 percent) and fuel technology/petroleum engineering (62 percent). Since many of these students will presumably return to their home

Figure 1-20
Percentage distribution of foreign students by major fields of study: 1981/82



See appendix table 1-38. Science Indicators—1982

Figure 1-21
Doctoral degrees awarded to foreign students as a percent of all doctoral degrees from U.S. universities by field



See appendix table 1-39. Science Indicators—1982

[125]See ref. 81.
[126]See ref. 82.

countries, this is an indicator of U.S. technical assistance and foreign citizens' interest in advanced U.S. scientific and technical training. Throughout the 1970's, over half the foreign students receiving S/E doctorates were from the Middle East and Asia. In 1980, only 0.1 percent were from the Soviet Union and the Eastern European countries, so this does not appear to be a main source of technology transfer to communist countries.[127]

The short-term impact of foreign citizens on the S/E doctorate labor force is small since many foreign students return to their home countries but could be significant in the future in some fields if present trends continue. About 10 percent of all foreign doctorate recipients in S/E fields in 1979 planned to remain in the United States, and in engineering fields one out of every three foreign doctorate recipients planned to stay. If these patterns continue in the 1980's, about one-sixth of the U.S. doctorate engineering labor force in 1990 could be foreign.[128]

While foreign advanced science and technology training in the United States has been increasing, U.S. students have been going abroad less. For example, the number and percent of U.S. doctorate recipients with plans to continue their training abroad peaked a decade ago in 1971 and now only constitutes about 1 percent.[129] Graduate training abroad is thought to be an important and broadening experience which helps to integrate U.S. scientists and engineers into the world scientific community and make them aware of important research being conducted elsewhere.[130] The decline in the number of U.S. postdoctoral students going abroad comes at a time when they, and therefore the United States, could benefit from the use of improved scientific facilities in Western Europe. It is also at a time when other countries are strengthening their S/T capabilities in many areas, and it is important to keep abreast of the latest developments in research abroad. U.S. graduates are foregoing foreign postdoctoral experience for a variety of reasons, undoubtedly including tenure concerns, employment considerations, and cost of living differences.[131]

Although study abroad or extended visits of 2 months to 1 year are judged to be the most useful way to learn new techniques and create future working relations, attendance at international meetings is also useful for establishing personal contacts, exchanging information, and obtaining the latest research results.[132]

Foreign Visitors to U.S. Laboratories

U.S. laboratories play an important role in international S/T cooperation. Results of a recent study of collaborative research surveying 14 Government, academic, and industrial laboratories are presented in table 1-9. The general conclusion reached is that most laboratories have had either a constant flow or an increase in foreign visitors over the last 5 years. Decreases were reported in only two cases—one due to cutbacks in accelerator operations.[133]

The largest program for visiting scientists among the laboratories surveyed was sponsored by the National Institutes of Health (NIH), which in 1979 had 417 visiting scientists, 163 guest workers, and 59 international researchers, from Western Europe and Japan. Over 40 percent of the visitors were from Japan, and almost 20 percent were from the United Kingdom. West Germany had a strong presence at the Jet Propulsion Laboratory, Oak Ridge, and Argonne. France was strongly represented at the Fermilab and Oak Ridge. Italy had a number of scientists at Argonne and Fermilab. According to U.S. scientists, the most effective type of visit involves long-term collaborative research between U.S. and foreign scientists. The long-term visits provide several benefits to U.S. scientists, including contact with fresh points of view, knowledge, or techniques. In almost every case, the results of this collaborative research are jointly published journal articles and specific plans for continued interaction, such as possible exchange of graduate students, plans for reciprocal visits, and future exchange of data and research results.[134]

Cooperation in S/T Literature

A tangible output of international cooperation in research is the jointly authored publication of scientific findings. Coauthorship is fairly common among scientists and engineers of the same organization, particularly in some fields where team efforts are prevalent. In general, collaboration is not as common among authors of different organizations and is even more rare between scientists of different countries, although it is more common in certain fields such as high energy physics. International cooperation in research occurs in a variety of modes or settings, and joint authorship of scientific papers can be a product of regional or international scientific centers, bilateral scientific agreements, or graduate study abroad. Attendance at international meetings can be a catalyst for international scientific cooperation.

An index of international research cooperation is presented in figure 1-22. Based on joint authorship between S/E's from different countries, this indicator shows that scientific cooperation has increased in all fields examined over the period—from 13 percent of all multiple-authored publications in 1973 to 16 percent in 1980. More than 42 percent of all multiple-authored publications in mathematics were internationally collaborative efforts in 1980, and over 30 percent of the joint publications in the fields of physics and earth and space sciences were also internationally coauthored. Much of the advanced physics work is now conducted at very large and unique facilities that are too expensive to duplicate in each country, so they have numerous visiting foreign scientists. The content of earth and space sciences is often global in nature and therefore necessitates collaboration between scientists of different countries. Mathematics is a field which is not facility-bound, and collaboration between individuals can be accomplished by exchanging papers and ideas.[135]

[127]See ref. 83, pp. 13-18, and ref. 84.
[128]See ref. 83.
[129]See ref. 85.
[130]See ref. 86.
[131]See ref. 87, pp. 12-14.
[132]See ref. 86, pp. 5-7.
[133]See ref. 88.
[134]See ref. 88.
[135]See the chapter on Advances in Science and Engineering for a discussion of how international cooperation and interaction in research on prime numbers has led to the solution of an age-old problem.

Table 1-9. Foreign[1] collaborative research in U.S. laboratory projects of six months to three years: 1980

Laboratory	Foreign visitors: Number	Foreign visitors: Trend
Stanford Linear Accelerator Center	200 per year	Increasing
Fermilab	10–40 per year	A decrease in last 5 years
Brookhaven	91 in 1980	Increasing
Argonne	Physical sciences: 60 in 1980	Increasing
Oak Ridge	120 per year	28% increase from 1971–75 period to 1976–80 period.
Jet Propulsion Laboratory	70 per year	Slight increase
National Center for Atmospheric Research	20–30 per year	Slight decrease in one division
Lamont-Doherty Geological Observatory	NA	No change
Woods Hole	NA	No change
Scripps	NA	No change
Salk Institute	NA	No change
Brain Research Institute	36–51 per year	51% increase, 1976–1980
National Institutes of Health	665 in 1980	Increasing
Bell Laboratories	40–60 per year	Slight decrease

[1] Includes only scientists from Western Europe and Japan.

NA = not available.

SOURCE: Anne S. Mavor "Trends in International Scientific Mobility: Foreign Scientists Visiting U.S. Laboratories" (Annapolis: W/V Associates), p. 10, and updated information from NIH.

Science Indicators—1982

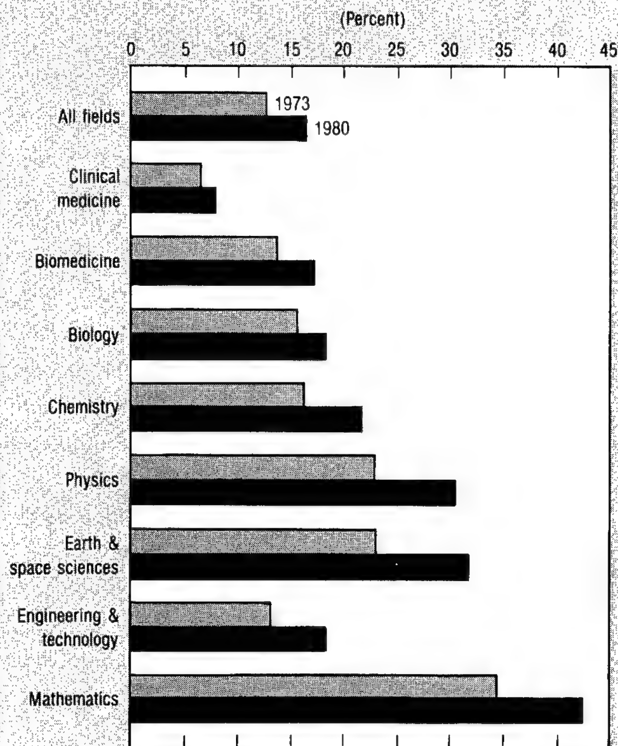
International cooperation and involvement have taken on increased importance as other nations have strengthened their S/T capabilities. International involvement is one way of keeping abreast of S/T developments in other countries. Figure 1-23 compares the level of U.S. scientific cooperative research with that of other countries based on percentages of jointly authored articles by scientists and engineers from different countries.[136] According to this indicator, West Germany, Canada and the United Kingdom maintain the highest levels of international cooperation in scientific research. The United States and Japan have the lowest ratios of international cooperative authorship—around 16 percent, which is less than half that of West Germany, the United Kingdom, and Canada.

The largest increases in scientific cooperation based on joint authorship were in the Soviet Union, most of which represented collaboration with Eastern Europe. West Germany and France also substantially increased their level of activity in international scientific collaboration by about 30 percent over the eight-year period. The United States did experience some growth in collaborative research as measured by this indicator. In 1980, the universities and colleges were the leading U.S. sector involved in international scientific coauthorship in six of the eight fields, and industry was the leading sector in the remaining two fields—clinical medicine and biomedicine.

Publication of technical articles in another country's journals also represents a type of scientific exchange or flow of ideas. The publication of articles by foreign scientists and engineers not only provides a forum for world class science but also enables a country's own scientific community to have ready access to the latest foreign research findings. The extent to which a nation publishes more foreign scientific findings than its own researchers publish abroad is an indication of its interest in and esteem of foreign research and also may be seen as an indication of its capacity to disseminate the world's scientific literature. Appendix table 1-42 shows that in 1980 the largest such balances in the

[136]Comparisons are made here with the seven countries that produce the largest proportion of the world's scientific and technical literature: the United States, the United Kingdom, the Soviet Union, West Germany, Japan, France, and Canada.

Figure 1-22
Index[1] of international cooperative research by field

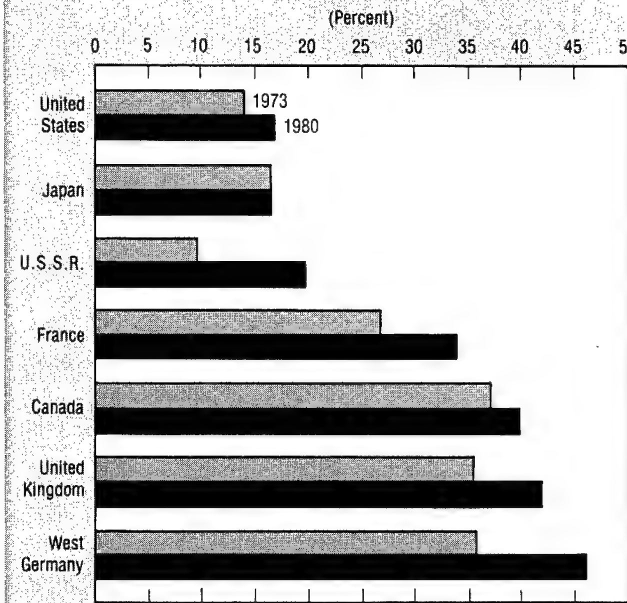


[1]Obtained by dividing the number of all scientific and technical articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations regardless of the country involved.

NOTE: Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

See appendix table 1-40. Science Indicators—1982

Figure 1-23
Index[1] of international cooperative research by country



[1]Obtained by dividing the number of all articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations regardless of the country involved.

NOTE: Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

See appendix table 1-41 Science Indicators—1982

United States were in chemistry and clinical medicine, followed by the fields of physics and engineering and technology. A great number of foreign articles are published in U.S. journals in the field of biomedicine, which is balanced by a large number of U.S. biomedical articles published abroad. The balance in physics has more than doubled since 1973, because foreign physicists only slightly increased the number of articles they published abroad.

U.S. Utilization of Foreign Science

Much can be learned from the scientific findings of other nations which now account for about two-thirds of the world's scientific activity. Therefore, it is important to the United States to be cognizant of foreign scientific results and to utilize them where appropriate. Table 1-10 demonstrates to what extent U.S. scientists and engineers utilize the rest of the world's research. In 1980, 44 percent of all citations found in U.S. publications were attributed to foreign publications. More than half of all references in U.S. chemistry and physics articles were to foreign scientific literature. U.S. utilization of foreign research findings in all fields has increased since 1973, with four fields showing increases of at least 5 percentage points: mathematics, biology, physics, and chemistry. From these data, it appears that U.S. scientists and engineers are familiar with and use foreign research findings. They also appear to have increased their usage of foreign science and engineering as other nations have increased their strength in these areas.

Table 1-10. Percent of all citations found in U.S. publications[1] that are to publications of other countries, by field: 1973 and 1980

Field	1973	1980
All fields[2]	42	44
Clinical medicine	36	39
Biomedical research	42	43
Biology	37	43
Chemistry	55	60
Physics	48	55
Earth and space sciences	36	39
Engineering and technology	40	44
Mathematics	40	47

[1] Based on the articles, notes and reviews in over 2,100 of the influential journals on the *1973 Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-13 for the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

U.S. scientists and engineers have cited United Kingdom research findings in chemistry 46 percent more than could be explained by the size of their literature base, and have cited U.K. research findings in mathematics 14 percent more, and in physics 10 percent more, than would be expected. (See appendix table 1-43.) Canadian research results are highly cited in the fields of chemistry, physics, and mathematics. West German literature in the fields of chemistry and physics is also highly utilized by S/E's in the United States.

Table 1-11 compares the U.S. use of a particular nation's research literature to all foreign usage. It shows that U.S. scientists and engineers are utilizing Canadian research literature a great deal more in every field than overall non-Canadian usage. This is undoubtedly affected by the factors of proximity and common language. U.S. use of Japanese S/T is similar to the world use in many fields with some exceptions; U.S. usage of Japanese literature is 12 percent less than foreign usage in the field of biology, but is 8 percent greater for the field of chemistry, and 6 percent greater in the area of engineering and technology. In general, U.S. use of research literature from West Germany and France is below world usage except in the field of physics. The use of United Kingdom literature by U.S. scientists and engineers is the same as foreign usage in physics and chemistry, and is 8 percent greater in mathematics.

OVERVIEW

What then are the main conclusions of these comparisons? On the resources side, the United States still maintains a much larger science and technology effort than most other industrial countries—both in terms of the amount of R&D expenditures and the number of scientists and engineers engaged in R&D. While there is no known optimal national level of R&D investment, it appears from the indicators presented here that the dominance of the U.S. relative investment position among major R&D-performing countries is somewhat lower than it was a decade ago. Other countries have increased their resources and thereby narrowed the gap. When comparisons are made in terms of the size of the economy or the size of the labor force, U.S. overall R&D investments are somewhat greater than those of other countries but less than those of Japan and West Germany for civilian R&D. It also appears that the general populace in certain other industrialized countries may have a higher level of scientific training than the U.S. population.

Output and impact indicators show that the United States still has a strong S/T enterprise. U.S. scientific literature is highly cited and so are U.S. patents in a number of fields. U.S. technology is sought by the rest of the world through licensing agreements and R&D-intensive trade. However, the United States has lost some of its competitive edge in terms of its contribution to the world's research literature, number of patents produced, and R&D-intensive world trade shares.

U.S. scientists and engineers contribute a high proportion (37 percent) of the world's influential scientific literature. This literature is also highly regarded by the world scientific community; it is cited 45 percent more than could be expected from its mere size although there has been somewhat of a decline in most fields in numbers of U.S. articles in influential journals.

Patent counts can be used as an output indicator of inventive activity, dominated by the industrial sector. U.S. domestic patenting dropped 40 percent since 1971, and U.S. patenting abroad also declined in terms of both share

Table 1-11. U.S. use of other nations' research literature as a percent of all foreign usage by field, for selected countries: 1980.

Field[1]	United Kingdom	West Germany	France	USSR	Japan	Canada
All fields	−4	−14	−9	−25	−4	+8
Clinical medicine	−9	−20	−10	−29	−1	+8
Biomedicine	−4	−10	−4	−8	−1	+2
Biology	−11	−17	−15	(2)	−12	+11
Chemistry	Same	−6	−1	−16	+8	+13
Physics	Same	+2	Same	−15	+3	+9
Earth & space sciences	−2	−9	−8	−18	−2	+4
Engineering & technology	−3	−16	−6	−14	+6	+11
Mathematics	+8	−8	−8	−15	−3	+9

[1] See appendix table 1-13 for a description of the subfields included in these fields.

[2] Cannot be calculated since the USSR biology articles in this set of journals is less than two percent of the world total.

NOTE: These comparisons of U.S. use of other nations' research literature are based on the "relative citation ratio", i.e., the ratio of a country's share of all the world's citations in a field to the share of its publications in that field. These relative citation ratios do not include citations from articles authored by researchers from the country being cited. For example, the U.S. relative citation index to Canadian chemistry is 1.37 compared to 1.21 for all non-Canadian countries as a group (1.37 ÷ 1.21 = 1.13 or 13 percent more usage by the United States than by other foreign nations).

See appendix table 1-43.

Science Indicators—1982

and absolute numbers. Foreign patenting in the United States increased between 1971 and 1974, remained relatively level afterwards, and in 1982 constituted over 40 percent of all U.S. patents.

The United States has a strong competitive advantage in R&D-intensive products, and is a net exporter of technology through various channels including exports, licensing agreements and foreign direct investment. While the United States remains technologically strong, there has been some change in its relative position due to increased foreign competition. The U.S. share of world exports of R&D-intensive products has decreased, with Japan and, to some extent, West Germany increasing their role in U.S. markets.

Science and technology activities impact on the economy in various ways. They have a positive effect on productivity and economic growth. While the United States still has the highest overall productivity levels in the world, U.S. productivity growth has slowed. From 1975 to 1982, manufacturing productivity grew more than four times faster in Japan, more than three times faster in France, and twice as fast in West Germany and the United Kingdom, than in the United States. Other countries, particularly Japan and West Germany, have increased R&D resources, have concentrated on civilian areas, and have incorporated embodied technology through new capital investments and utilization of technological advances to a greater extent than has the United States.

The United States has been a contributor to world science, particularly through the training of foreign S/E's and the support of joint research projects. Foreign students have come to the United States in increasing numbers for scientific and technical training although they constituted only 2.6 percent of the total enrollment in 1981-82. There are significant variations among fields. For example at the extreme, currently there are almost double the number of foreign engineering students and more than two and one-half times the number of students in mathematics and computer sciences than there were in the mid-1970's. Most of the foreign students are from developing countries—over 32 percent from Asia, 17 percent from Latin America, and 13 percent from Africa. In engineering, foreign students constitute over half of the doctorate recipients, and one out of three of these foreign engineers plan to remain in the United States.

As other countries have increased their scientific and technical capabilities, economic competition has increased, but so have the opportunities for advantageous U.S. participation in international S/T activities. The United States and Japan have the lowest ratios of international cooperative authorship—less than half that of West Germany, the United Kingdom, and Canada. However, U.S. scientists and engineers have increased their level of international coauthorship. U.S. scientists and engineers do utilize the rest of the world's research. In 1980, 44 percent of all citations found in U.S. publications were to foreign publications. It may now be important for the United States to be even more aware of foreign research and be involved in international science and technology activities from the standpoint of a recipient as well as of a donor. In an era of limited resources, coupled with expanding technical horizons, new institutional arrangements for cooperation in science are of growing interest in scientifically advanced countries.

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Chapter 2
Support for U.S. Research and Development

Support for U.S. Research and Development

HIGHLIGHTS

- National expenditures for research and development (R&D) are expected to grow in constant-dollar terms at an average annual rate of 4.0 percent between 1980 and 1983. Rapid expansion of industrial support for research and development accounted for much of this growth, increasing at an average annual rate of 5.4 percent in constant-dollar terms. (See pp. 42-43.)
- The ratio of national R&D expenditures to gross national product (GNP) is expected to reach 2.65 percent in 1983, up from a 20-year low of 2.23 percent in 1978. Much of the growth in the ratio is related to a slowing of GNP growth relative to the steady expansion of national R&D expenditures. (See p. 42.)
- In 1980, industrial sources of R&D expenditures exceeded Federal Government sources for the first time in the last two decades. The industrial sector has thus become the largest single source of R&D support in the United States—principally in the area of development. Furthermore, between 1980 and 1983, industrial R&D spending is expected to grow at a higher rate than any other source of R&D support—an average annual constant-dollar rate of 5.4 percent, compared to a rate of 3.1 percent for the Federal Government and an average annual decline of 2.4 percent for all other sectors combined. (See pp. 42-43.)
- While national expenditures for development are expected to grow at an average annual rate of 4.3 percent in constant-dollar terms between 1980 and 1983, national support for research (both basic and applied) expanded at an estimated average annual rate of 3.5 percent. In 1983, national expenditures for development will probably reach $26 billion in 1972 constant dollars, up from a level of $23 billion in 1980. National constant-dollar expenditures for research are likely to grow from a little over $12 billion in 1980 to nearly $14 billion in 1983, as the growth in industrial constant-dollar support for both basic and applied research is accompanied by slight gains in Federal constant-dollar support in those areas. (See pp. 45-47.)
- Federal support for R&D in constant-dollar expenditures rose at an estimated average annual growth rate of 3.1 percent between 1980 and 1983, after growing at an average annual rate of 2.5 percent between 1975 and 1980. Much of this Federal R&D growth is related to an anticipated 15 percent growth in constant-dollar support for development, primarily for defense. Between 1980 and 1983, however, Federal expenditures for research are also expected to grow by 1.9 percent in constant-dollar terms. (See p. 43 and pp. 45-47.)
- National defense R&D (including the atomic energy defense activities of the Department of Energy) is expected to account for 64 percent of 1983 total Federal budget authority for R&D, up from a level of 47 percent in 1980. A 13-percent increase is expected in defense R&D between 1982 and 1983 alone. This restores it to approximately the level last reached in 1967 (in constant-dollar terms). Defense-related R&D is expected to expand to 70 percent of the total Federal R&D budget authority by 1984. (See p. 51.)
- Federal R&D programs in non-defense areas are expected to decline in the aggregate between 1982 and 1984, as the administration's policy of taking the Government out of commercial demonstration projects is implemented. Much of this support will be reallocated to basic research support, which will experience a 22-percent increase during that time. (See pp. 51-54.)
- Federal outlays for R&D and R&D plant have declined as a share of total Federal outlays, to 6 percent in 1983 from a peak of 13 percent in 1965. Although Federal R&D and R&D plant outlays have risen at an average annual rate of 7.9 percent between 1970 and 1983, the greater expansion of Federal outlays in other areas—such as benefit payments to individuals—have outpaced the continued growth in Federal R&D spending. However, as a proportion of controllable outlays, Federal outlays for R&D and R&D plant grew from a level of 12 percent in 1980 to 14 percent in 1983. (See p. 55.)
- Between 1967 and 1981, annual changes in the magnitude and direction of Federal R&D expenditures reveal a significant positive correlation with private sector R&D investment changes occurring 1 year later. This suggests that there may be a relationship between Federal R&D spending and the subsequent growth or decline in non-Federal R&D expenditures. (See p. 50.)

An important aspect of the economic adjustment now underway in the United States is the continued expansion of national support for research and development (R&D), even in constant-dollar terms. The principal reason for this trend is clear. It is generally accepted that new developments in science and technology will play an important part in maintaining the vitality of the American economy.

One concern that motivates increases in R&D support, especially in the private sector, is productivity growth. While the forces underlying productivity advance are complex, science is recognized as essential to industrial innovation and productivity.[1] Research may lead to productivity improvements both in the industries in which R&D is conducted, and in the industries using new products that result from these activities.[2] Moreover, R&D can lead to entirely new products and processes that improve our standard of living. Sustained, vigorous investment in research and development thus serves as one means to induce productivity growth.

Another factor in the continuing growth of total national R&D support is the commitment of the Federal Government to the strengthening of national defense capabilities. After 15 years of decline in real terms, defense-related R&D funding grew by an annual average rate of about 18 percent between 1980 and 1983. Indeed, defense-related R&D spending is estimated to account for nearly all of the aggregate Federal R&D funding growth between 1982 and 1983.[3] R&D expenditures are expected to accelerate development of defense-related technologies, such as advanced computer software and aircraft engines, and to support long-range research that may lead to defense applications, such as microelectronic circuitry and metal-matrix composite materials.[4]

Numerous resources are needed to conduct research and development activities, including adequate levels of funding and skilled personnel. The indicators presented in this chapter analyze recent trends in funding support for research and development. Areas are identified in which changes may be expected in existing patterns of support, with special consideration given to the potential impact of those changes on U.S. science and technology. Other chapters of this report explore trends in the supply of qualified scientists and engineers, and changes in the research environment in specific R&D sectors, such as industry and universities and colleges. Taken together, these chapters summarize the present condition of national resources for research and development.

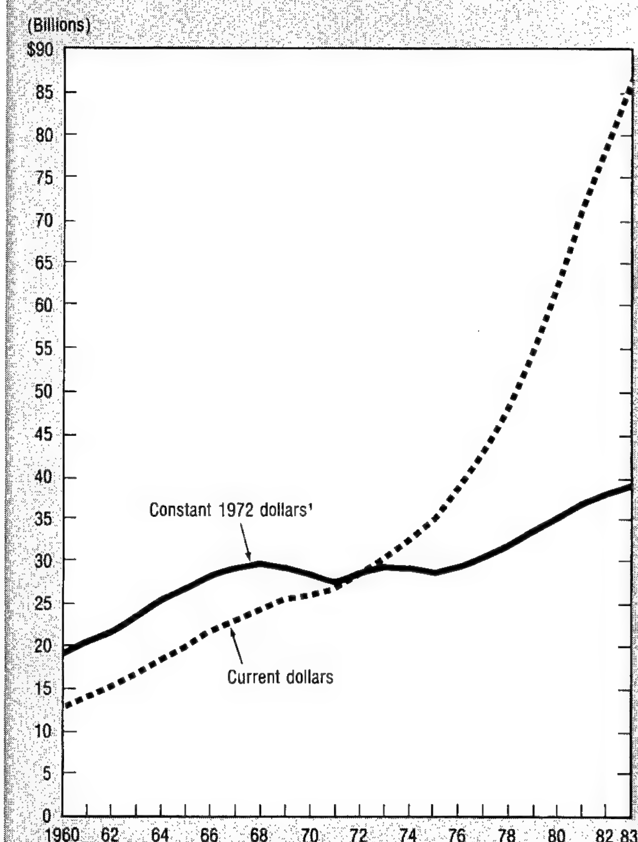
NATIONAL EXPENDITURES FOR R&D

National R&D expenditures have grown steadily since 1960, reaching a level of approximately $73 billion in 1981. (See figure 2-1.) Estimates suggest this growth will continue through 1983, bringing these expenditures to a level of $87 billion in that year.

High inflation rates have had a substantial impact, however, on the purchasing power of R&D funds. National expenditures for research and development, for example, will have increased sixfold in current-dollar terms between 1960 and 1983, but this increase will represent less than a doubling after adjusting for inflation.[5]

Following a period of low growth in the first half of the 1970's, national expenditures for R&D have grown at an average annual rate of about 12 percent since 1975 in cur-

Figure 2-1
National R&D expenditures



[1]GNP implicit price deflators used to convert current dollars to constant dollars.
NOTE: Estimates are shown for 1981, 1982 and 1983.
See appendix table 2-2. Science Indicators—1982

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[1]Since the role of innovation in the business cycle was first described in 1939, numerous authors have explored the relation of science and technology to economic growth. See, for example, refs. 1, 2, 3, and 4.

[2]See ref. 5.

[3]See ref. 6.

[4]See ref. 7, pp. 32-38, and ref. 39, pp. K-7 and K-8. Access to modern instrumentation is a prerequisite for progress in all of these areas. A recent study by the National Academy of Sciences concluded, for example, that powerful computers are necessary to advance theoretical understanding of many materials. See ref. 45, pp. 129-133.

[5]R&D expenditures are frequently used as an indicator of R&D activity. The use of dollars is particularly sensitive to distortion caused by inflation. The analysis which follows, therefore, is conducted in constant-dollar terms. In the absence of a specific R&D price deflator, the implicit price deflator for the gross national product (GNP) has been used to convert current dollars to constant dollars, with 1972 serving as the base or reference year. The estimated rate of inflation in the U.S. economy for 1982 was 4.6 percent (GNP deflator). See appendix table 2-1, and ref. 43, p. 2-3.

rent-dollar terms. (See figure 2-2.) This rate of growth, furthermore, exceeds that observed between 1960 and 1968, a period in which substantial efforts were made to strengthen our scientific and technological capabilities in response to the "Sputnik challenge." A different picture emerges, however, after adjusting for inflation. Between 1975 and 1980, the average annual rate of growth in national R&D expenditures in constant-dollar terms was lower than that between 1960 and 1968 (4.5 percent vs. 5.3 percent, respectively), and is expected to slow even further between 1980 and 1983 (4.0 percent). The constant-dollar growth rate is expected to increase once again, however, in the mid-1980's.[6]

The ratio of national R&D expenditures to the GNP shows how much of the Nation's resources are devoted to research and development activities. During the last two decades, the R&D-to-GNP ratio was at its highest point in 1964 when it reached 2.96 percent. (See figure 2-3.) At that time an unusually large proportion of Government fiscal resources was utilized for strengthening scientific and technological capabilities—especially in the area of defense and space R&D. As space programs subsequently reached their objectives, or were scaled back or dismantled, the R&D/GNP ratio dropped to a low of 2.23 percent in 1978. The ratio has climbed once again to 2.45 percent in 1981, and is expected to reach 2.65 percent in 1983. In contrast to earlier years, however, the recent increase in the R&D/GNP ratio does not stem completely from significant channeling of national resources into major new science and technology thrusts. It results instead from a slowing of GNP growth relative to the steady expansion of R&D expenditures.[7]

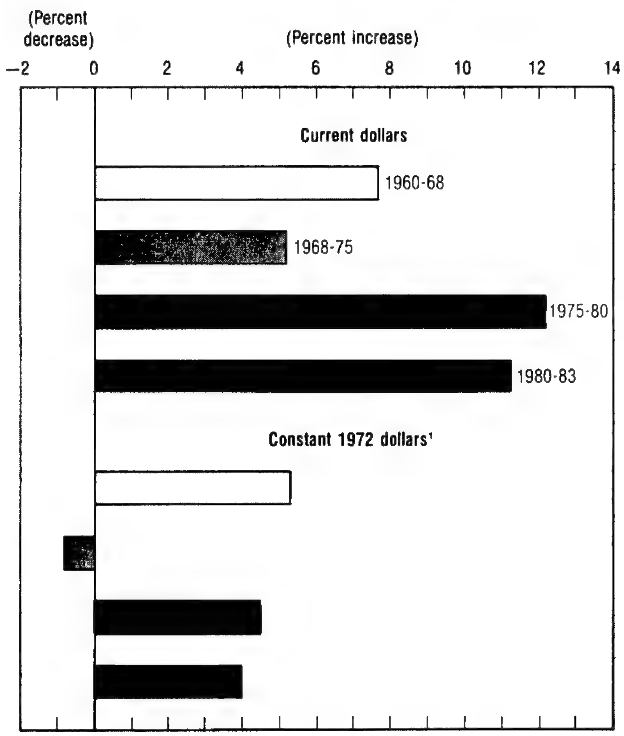
Non-Federal R&D expenditures more closely parallel changes in the GNP than Federal R&D expenditures. (See figure 2-4.) This isn't surprising because decisions by the private sector to invest in research and development are influenced by the state of the economy. Federal investment, on the other hand, is chiefly motivated by an interest in supporting R&D activities addressed to long-range national problems, although considerations of the national economy have come to play an increasingly important role in the rate of growth of Federal R&D support.

In summary, national investment in R&D activities has been increasing, even in constant dollars since the mid-1970's. This growth is significant considering the fact that the GNP has been declining or growing at a very low rate during that period. The sections that follow address the sectoral distribution of financial support for R&D, where that R&D is carried out, and the kinds of R&D performed.

Sources of Support for Research and Development

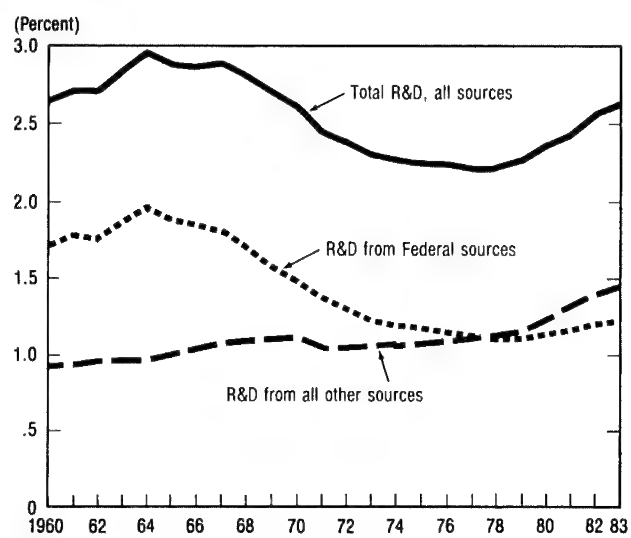
Important changes have come about in national patterns of R&D support. Both Federal and industrial R&D fund-

Figure 2-2
Average annual rate of change of national R&D expenditures



¹GNP implicit price deflators used to convert current to constant 1972 dollars.
Based on appendix table 2-2. Science Indicators—1982

Figure 2-3
National R&D expenditures as a percent of GNP by source

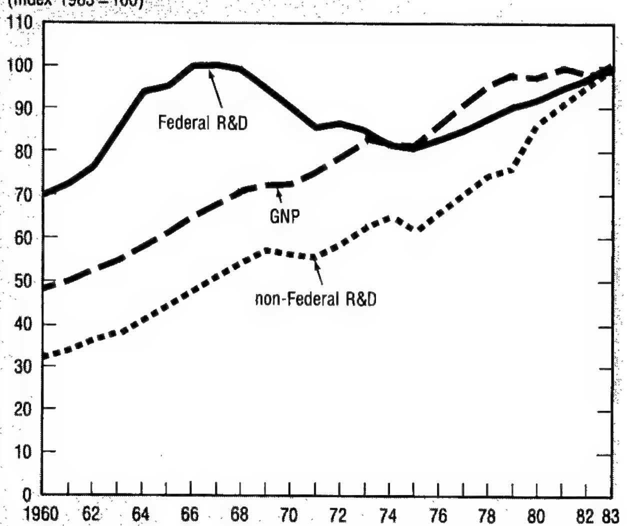


NOTE: Estimates are shown for 1981, 1982 and 1983.
See appendix table 2-2. Science Indicators—1982

[6]See ref. 10.

[7]See appendix table 2-2. It has been pointed out that the U.S. ratio of R&D expenditures to GNP has generally increased at a decelerated rate when assessed over a longer time period. The ratio doubled during the 1920's, doubled again in the 1930's, but increased by only one-half in the 1940's, again in the 1950's, and actually declined by about one-tenth between 1960 and 1980. See ref. 35, pp. 108-110.

Figure 2-4
Relative change of GNP and Federal and non-Federal R&D expenditures in constant 1972 dollars[1]



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
Based on appendix table 2-2.

Science Indicators—1982

ing have grown in recent years, but in 1980, industrial R&D spending exceeded Federal R&D spending for the first time in over two decades. Between 1980 and 1983, furthermore, industrial R&D support is estimated to be growing at an average annual rate of 5.4 percent (in constant dollars), compared with an estimated average annual growth rate of 3.1 percent for Federal support. Between 1975 and 1983, Federal expenditures will have grown, however, at an estimated average annual rate of 2.7 percent, thus reversing a 10-year constant-dollar funding decline which began in the mid-1960's. (See figure 2-5.)[8]

Each sector of the economy has its own needs and reasons for funding research and development. The Federal Government, for example, supports R&D activities that meet the needs of the Nation in areas where private sector support may not be forthcoming. This includes research and development in which the Government is the sole or the primary user—such as R&D for national defense, space activities, or environmental regulation purposes. A little over half the fiscal year 1983 Federal R&D funds are estimated to be directed to industrial performers (see figure 2-6), with the next largest share utilized for intramural R&D carried out by Federal personnel.

The Federal Government is unique in the extent to which it distributes R&D dollars across all performing sectors, but the private sectors also serve as important sources of support. The industrial sector, for example, has in recent years invested more in R&D than the Federal Government. About 2 percent of industrial R&D funding, or $700 million, has been directed to academic and other nonprofit institutions in recent years.[9]

Although the academic sector and nonprofit institutions together provide only 3 percent of total national support for research and development, they serve as special R&D resources in the science community. R&D investment decisions by these sectors often satisfy R&D funding needs seldom met by the grants programs of the Federal Government or the industrial sector. For example, philanthropic R&D spending—about half of which is disbursed through gifts, grants, or contracts to universities—is often directed toward the solution of problems of special interest to the donor, such as research on rare diseases or studies of the quality of our educational system. In the academic sector, essentially all of its own R&D investment is used in-house to augment on-going investigations or to provide "seed money" for junior faculty.

Changes in existing patterns of R&D spending by these various funding sources are expected during the 1980's. Of all the sources of R&D support, industrial expenditures are estimated to grow at the most accelerated rate between 1980 and 1983, although the health of the economy will be a factor determining the magnitude of the growth rate. (See figure 2-7.) Federal R&D spending is likely to grow at more modest rates, while R&D support provided by the academic sector and by nonprofit institutions is expected to decline.

Performers of Research and Development

The institutions that serve as sources of R&D support are not necessarily the same ones that perform it. Federal R&D support is distributed across such a wide range of non-Federal performing sectors that a different picture emerges when national expenditures for research and development are considered in terms of who carries out the R&D activities.

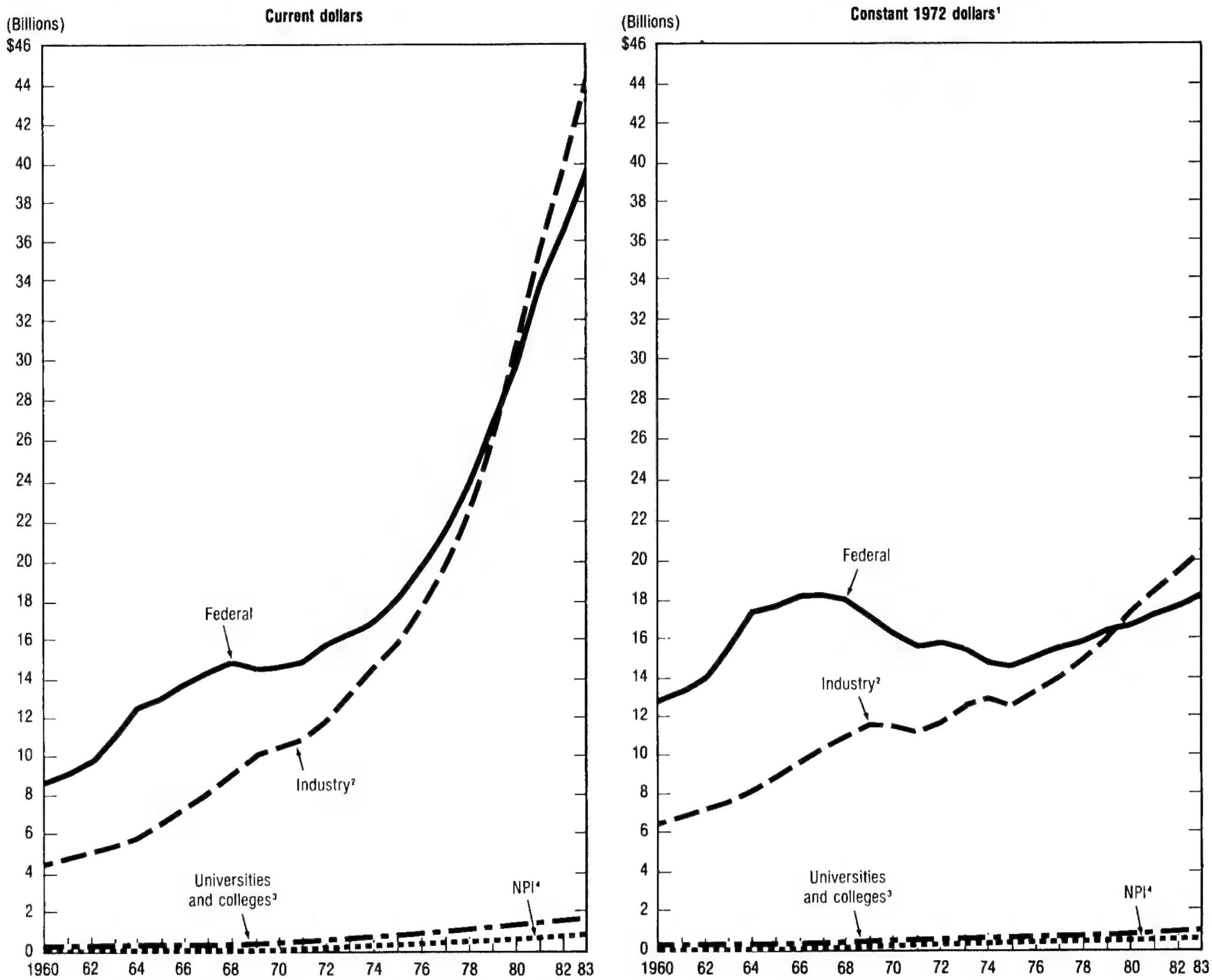
The industrial sector performs the vast majority of the research and development in the United States, accounting for an estimated 74 percent of all R&D expenditures in 1983. After a period of substantial real growth in the 1960's, industrial R&D performance declined by nearly 9 percent in constant dollars between 1969 and 1975. (See figure 2-8.) Between 1975 and 1981, industrial R&D expenditures from all sources grew nearly 38 percent in constant dollars, attributable primarily to expanded company investment. Company funding for R&D grew by 47 percent in constant dollars during that period, about twice the 23 percent increase in Federal support for industrial-based R&D. Industrial R&D expenditures are estimated to have grown by another 5.2 percent per year in constant-dollar terms between 1981 and 1983.

Federal intramural activity is the second largest area of R&D performance in the United States. In 1983, it is expected to account for 11 percent of national R&D expenditures—over $4.4 billion in constant dollars. More than half of these R&D expenditures represent research and development carried out by the Department of Defense (DOD). The National Aeronautics and Space Administration (NASA) and the Department of Health and Human

[8]Throughout the chapter it should be noted that reports of R&D expenditures for 1983 represent estimates.

[9]See ref. 12, and unpublished data.

Figure 2-5
National expenditures for R&D by source



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Data are not available on industry resources for research in the psychological and social sciences.
[3]Includes state and local government sources.
[4]Other nonprofit institutions.
NOTE: Estimates are shown for 1981, 1982, and 1983.
See appendix table 2-3.

Science Indicators—1982

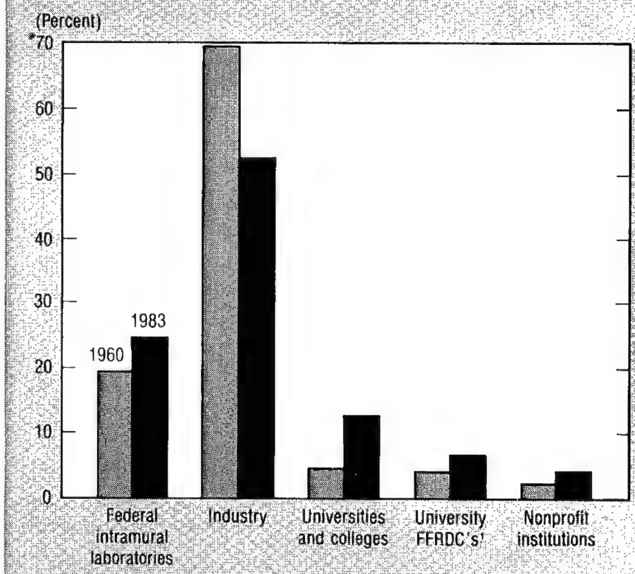
Services (DHHS), chiefly through the National Institutes of Health, account for another 14 percent and 9 percent of Federal intramural research obligations, respectively. Between 1980 and 1983, Federal intramural R&D expenditures are estimated to have increased at an average annual rate of about 0.5 percent in constant-dollar terms.

The constant-dollar expenditures for each of the three remaining R&D performing sectors are estimated to have shown some declines compared to 1983 levels. After increasing at an average annual rate of 12.0 percent in the 1960's, the growth of academic R&D expenditures decreased to an average annual growth rate of 2.8 percent between 1970 and 1980. Academic constant-dollar expenditures are estimated to decline slightly between 1980 and 1983 at an average annual rate of about 0.2 percent. These changes are related to an anticipated decline in Federal support for academic R&D in constant dollars as increased R&D spending by that source is offset by the effects of inflation.[10]

Between 1980 and 1983, funding for university-affiliated federally funded research and development centers

[10]Trends in support for academic R&D will be analyzed more closely as part of the review of academic science and engineering in chapter 5 of this report. See also ref. 9.

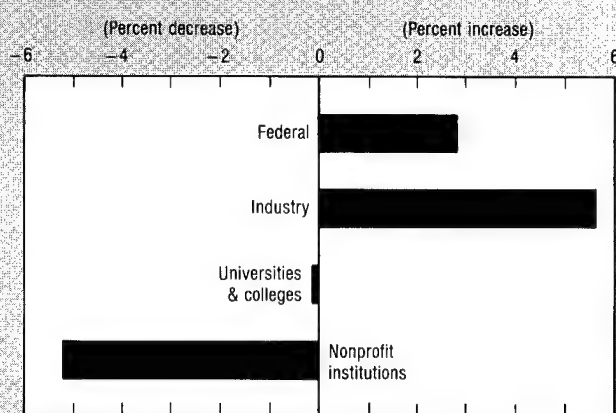
Figure 2-6
Proportion of Federal R&D expenditures reported by performing sectors



[1]University-affiliated federally funded research and development centers. See appendix table 5-15 for a list of these centers.
SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319), p. 24, and unpublished data.

Science Indicators—1982

Figure 2-7
Average annual percent change in constant-dollar[1] R&D expenditures by source: 1980-1983



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
Based on appendix table 2-3.

Science Indicators—1982

(FFRDC's)[11] is also estimated to decline by an average rate of about 2 percent each year in constant dollars. Expenditures in the nonprofit sector—almost half of which represent the work of six FFRDC's administered by nonprofit institutions—are also expected to decline.

Character of Research and Development

Research and development encompass an extremely broad spectrum of activities, ranging from the search for new knowledge to the development of new technologies. While the boundaries are by no means clear, it is possible to analyze national R&D expenditures in terms of the intended purpose of the scientific activity. Thus, research and development may be distinguished on the basis of advancement of fundamental scientific knowledge (basic research), practical or commercial application (applied research), or generation of new products and processes (development).[12]

Development Component. Development accounts for nearly two-thirds of total R&D expenditures in the United States. (See figure 2-9.) The vast majority of the development activities are carried out in the industrial sector, approximately 87 percent, for example, in 1983. The concentration of development activities in the industrial sector is not surprising since the goal of all industrial activity is ultimately the production of new or improved products or processes. The aircraft and missile, electrical equipment, and machinery industries have accounted for over 60 percent of all industrial R&D funds devoted to development in recent years.[13] Similarly, the predominance of defense spending in the Federal R&D budget reflects in part the Government's position as principal customer and, therefore, appropriately, the funder of development as well as research.

Following an 8-year period of few or no increases, national funding for development accelerated to an annual average growth rate of 4.5 percent between 1975 and 1981. Some of this growth was stimulated by Federal support for energy demonstration projects in a number of areas, both nuclear and non-nuclear, and some was stimulated by NASA support for the Space Shuttle program.[14] Both of these sources of growth are now in decline; the former because the responsibility for commercial demonstration projects[15] is being transferred to the private sector, and the latter because the Space Shuttle is now operational and no longer considered a development program. National expenditures for development will have grown on average by another 4.5 percent each year between 1981 and 1983 in constant-dollar terms as DOD development funding is significantly raised.

[11]Federally funded research and development centers (FFRDC's) are laboratories established outside the Government whose purpose it is to conduct R&D under the direct sponsorship of a Federal agency. Data are presented here for those FFRDC's administered by universities. Information regarding those FFRDC's administered by industrial firms or nonprofit institutions is included in the totals for the relevant performing sectors and is not broken out separately.

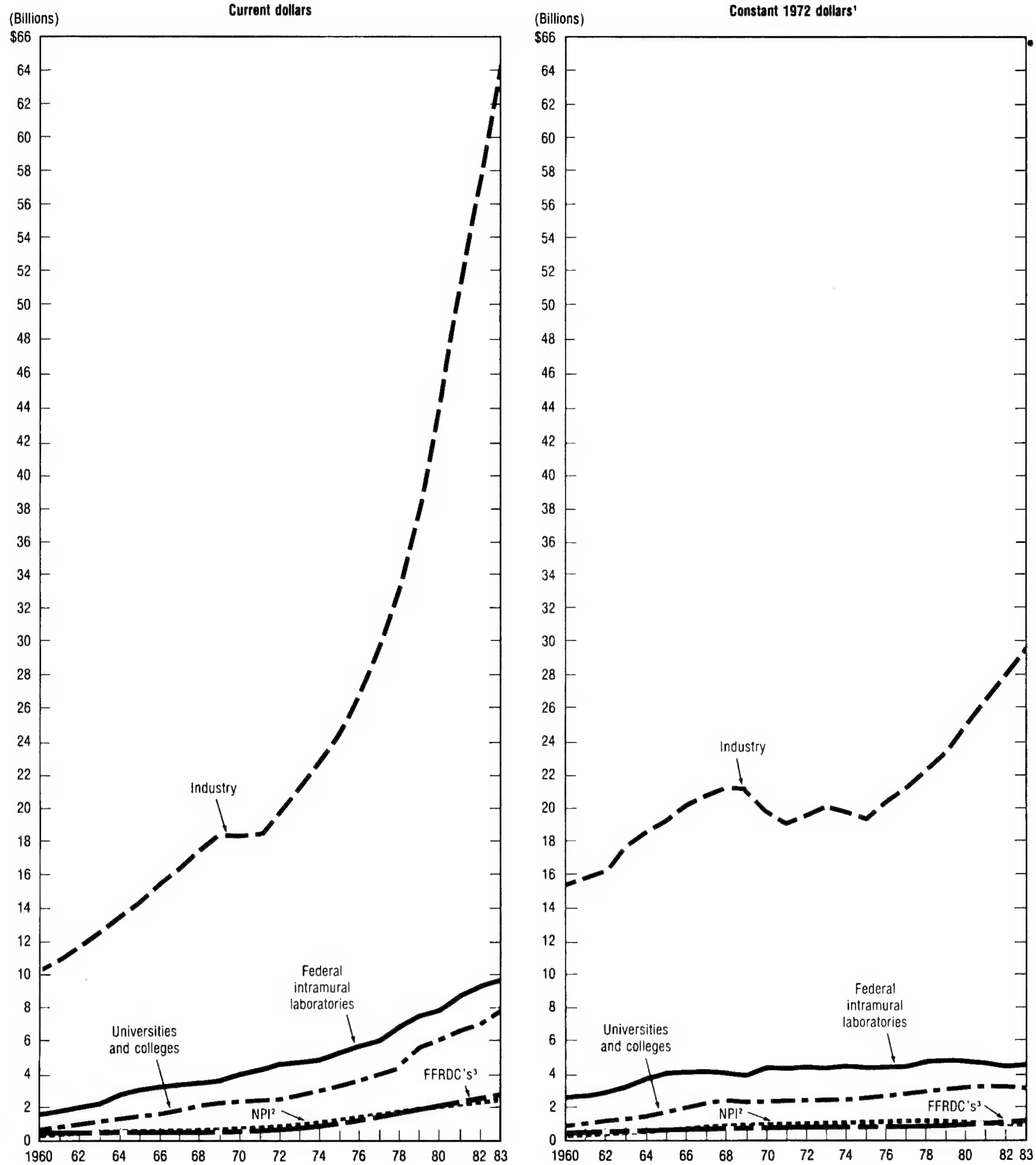
[12]Definitions of the terms used by the National Science Foundation (NSF) in its data collection activities may be found in appendix table 2-5. Distinguishing between basic and applied research and between applied research and development is not always easy. A particular research effort may be identified as "basic" or as "applied" depending on whether the classification is made by the research sponsor, by the performing organization, or by the individual performing the work. See ref. 14.

[13]See ref. 13, pp. 8-9.

[14]See ref. 12. The Space Shuttle is now in its operational phase. Recent R&D budget estimates for NASA therefore exclude funding for production and operation of the Shuttle, but continue to include R&D funds for certain modifications and improvements to the Shuttle. See ref. 39, p. K-9.

[15]See, for example, ref. 47.

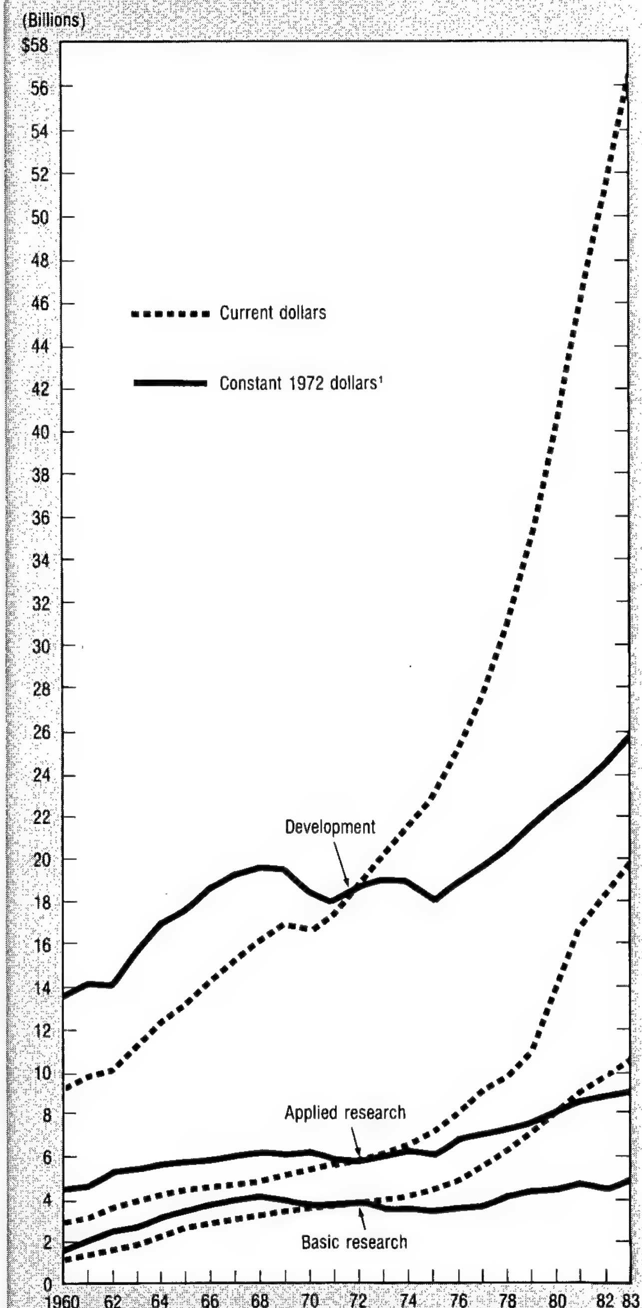
Figure 2-8
National expenditures for R&D by performer



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Other nonprofit institutions.
[3]Federally funded research and development centers administered by universities.
NOTE: Estimates are shown for 1981, 1982 and 1983.
See appendix table 2-4.

Science Indicators—1982

Figure 2-9
National R&D expenditures by character of work



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1981, 1982 and 1983.
See appendix table 2-5.

Science Indicators—1982

Research Component. Over the years, there has been almost no change in the balance between national support for research and for development. In 1960, development accounted for nearly 69 percent of all R&D expenditures, with applied research representing 22 percent, and basic research 9 percent. In 1983, development is expected to account for 65 percent of total national R&D expenditures, with applied research and basic research at levels of 23 percent and 12 percent, respectively. Research, both basic and applied, represents about one-third of total national R&D expenditures, with applied research accounting for about 65 percent of the research total. The industrial sector was estimated to have performed about 50 percent of the research supported in 1983, with the next largest performer being the academic sector (25 percent).[16]

The Federal Government provides more than half the funds for research in the United States (see figure 2-10), over 50 percent of which was performed as applied research. (See appendix tables 2-7 and 2-8.) Another 42 percent of national research expenditures is provided by industry, 85 percent of which is directed toward applied research. Total national support for research is estimated to increase by nearly 2.6 percent in current dollars between 1982 and 1983, with the industrial contribution growing at an estimated rate of 4.6 percent. (See appendix table 2-6.)

Some changes have taken place in patterns of support for research, as well as for development. With regard to Federal funding, development is expected to grow by 4.3 percent in constant dollars between 1982 and 1983. (See figure 2-11.) While Federal constant-dollar support for applied research is estimated to remain about the same, Federal expenditures for basic research are expected to grow by 1.9 percent in 1983 in constant-dollar terms. This reverses a slight downturn in Federal constant-dollar support for basic research that occurred between 1981 and 1982.

Industrial R&D expenditures are expected to grow by about 5 percent in constant-dollar terms in all three categories between 1982 and 1983, with the greatest growth occurring in industrial support of basic research (up an estimated 5.8 percent between 1982 and 1983).

The primary source of support for basic research in the academic sector is the Federal Government, about 70 percent of the total. Federal support for basic research in the academic sector is expected to grow by just under 1 percent in current-dollar terms between 1982 and 1983.

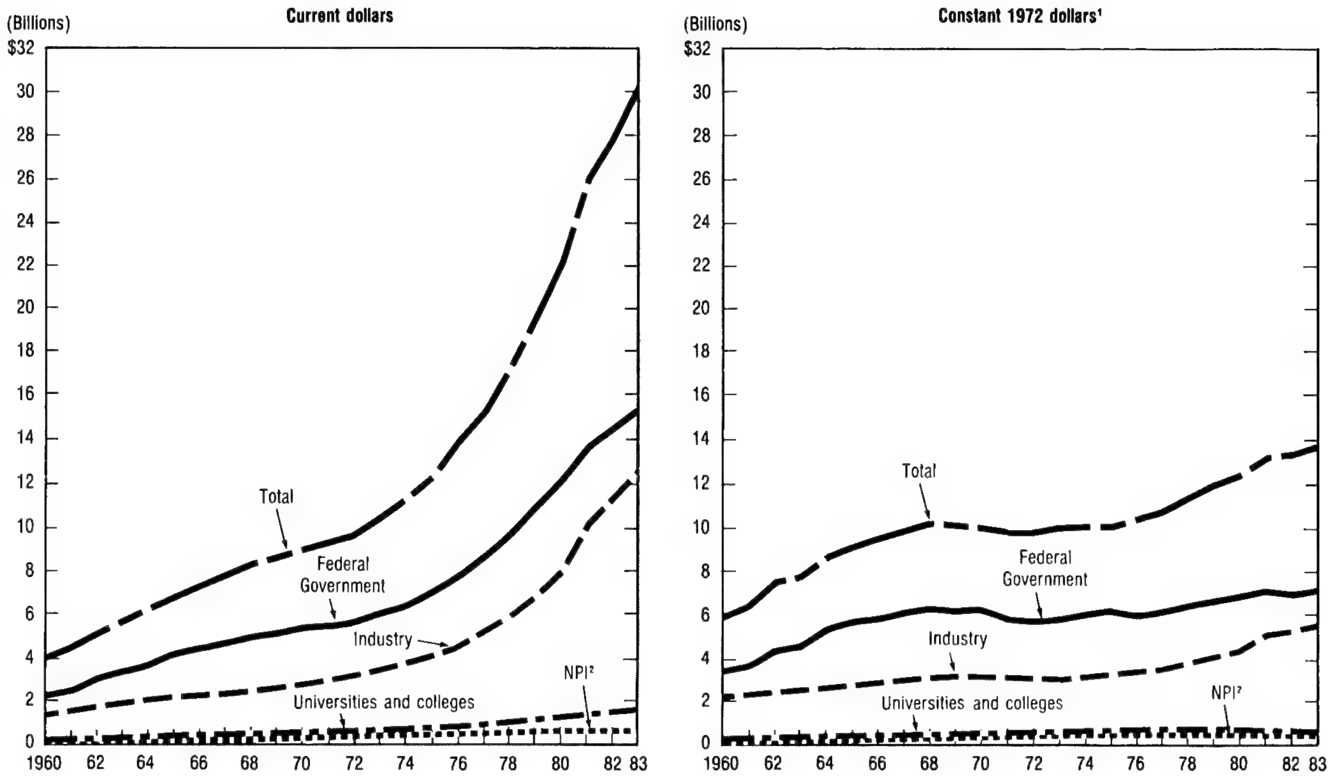
TRENDS IN FEDERAL SUPPORT FOR RESEARCH AND DEVELOPMENT

Science and technology in the United States continue to benefit from the infusion of substantial sums of Federal dollrs for research and development. Growth in Federal R&D support has not kept pace with industrial R&D spending growth in recent years. Nonetheless, Federal R&D investment continues to grow. This section explores the nature of recent changes in the Federal R&D budget and the factors that have influenced those trends.

The Federal Government does not have a separate R&D budget. Rather, Federal funding for R&D is the sum of those program requests submitted by individual agencies to the Office of Management and Budget (OMB), subsequently by the President to Congress, and approved during the budget review and appropriation process. Agency requests are reviewed in terms of the importance of the R&D request to the missions of the agency.

[16]See ref. 12.

Figure 2-10
Total research expenditures by source



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Nonprofit institutions.
NOTE: Estimates are shown for 1981, 1982 and 1983.
See appendix table 2-6.

Science Indicators—1982

Most R&D funds are part of larger appropriations and do not show up as line items in the budget. R&D support is thus often influenced by broader policy considerations. In recent years, for example, the Federal Government has placed considerably less emphasis on energy demonstration programs that it has determined are well within the capability of private industry, thereby reducing the magnitude of Federal support for energy research and development.[17]

Under present economic policies, the Federal Government is seen as having two main responsibilities with regard to R&D support to meet national needs: (1) providing a climate for technological innovation that encourages private sector R&D investment, and (2) supporting those areas where there is substantial prospect for significant economic gain, but where private sector support may not be forthcoming.[18] With those funding goals in mind, the sections that follow explore recent trends in Federal support for research and development.

Federal Outlays for R&D

Federal outlays for research and development and R&D plant will reach an estimated $42.4 billion in 1983. (See appendix table 2-10.) This total is 5.6 percent of the outlay total shown in the 1983 Federal budget. (See figure 2-12.) The level of Federal outlays[19] for research, development, and R&D plant peaked at $17.0 billion in 1968, subsequently declining to $15.7 billion in 1970. From 1970 until 1982, Federal R&D and R&D plant outlays have risen at an estimated average annual rate of 7.9 percent, although in constant-dollar terms, the nadir occurred in 1975.

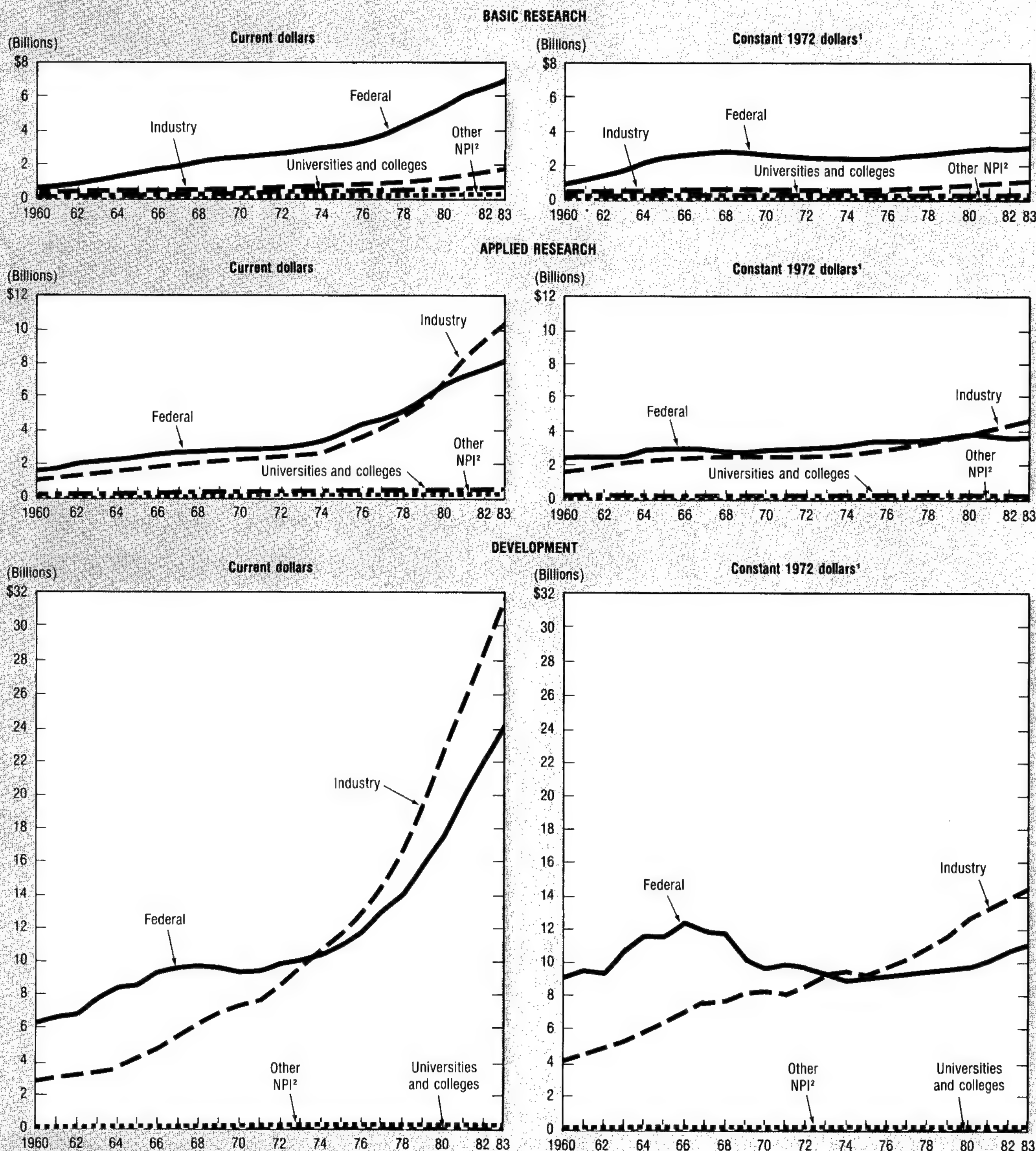
The ratio of Federal R&D and R&D plant outlays to total Federal outlays does not reflect, however, this signi-

[17]In his budget message to the U.S. Congress in 1982, President Reagan pointed out that reduced subsidies to business for energy technology development and commercialization represented the kinds of steps that could be taken to realize savings in domestic discretionary expenditures. See ref. 15, p. M-17, and ref. 32.

[18]See ref. 11, pp. 3-4.

[19]Government agencies are permitted to commit Federal funds for research and development or any other program only when they have been authorized to do so by law. Once authorized, usually in the form of appropriations, funds are obligated by the agencies to intramural personnel, or to extramural contractors or grantees. In the case of intramural payments, obligations and outlays are very close. In the case of extramural payments, considerable lags occur. In periods when R&D obligations are rising, the outlay totals will rise later, although trends will be approximately the same. These distinctions differ from "expenditure" data presented elsewhere in this chapter. These expenditure data, as far as Federal support is concerned, are derived from information reported by R&D performers, such as the academic sector or the industrial sector.

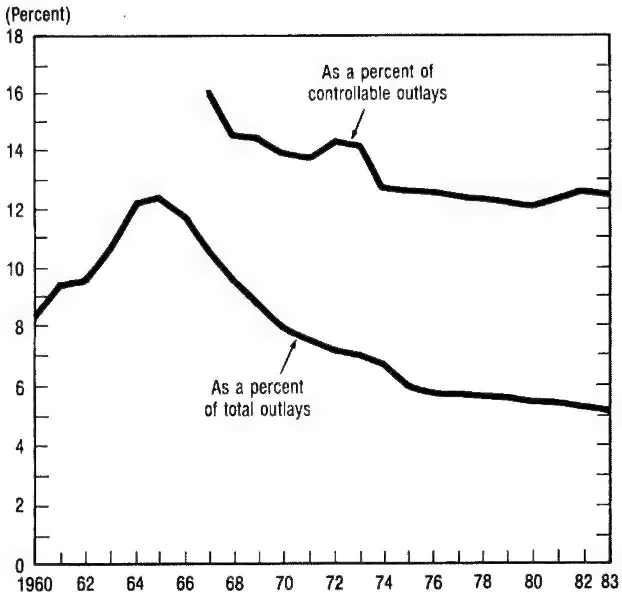
Figure 2-11
National R&D expenditures by character of work and source of funds



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Other nonprofit institutions.
NOTE: Estimates are shown for 1981, 1982, and 1983.
See appendix tables 2-7, 2-8, and 2-9.

Science Indicators—1982

Figure 2-12
Federal outlays for R&D and R&D plant as a percent of total Federal budget outlays and as a percent of the relatively controllable portion of the Federal budget



See appendix table 2-10. Science Indicators—1982

ficant growth pattern, revealing instead a drop from 13 percent at its peak in 1965 to approximately 5 percent in 1982. The fact is there has been a great expansion of Federal outlays in areas other than R&D support. For example, benefit payments to individuals, including retirees, the poor, the unemployed, and the disabled, grew more rapidly in the 1970's than any other budget category. These benefit payments represented an estimated 47 percent of total Federal outlays in the 1983 budget.[20]

Benefit outlays and similar payments represent relatively uncontrollable parts of the Federal budget.[21] As a proportion of controllable outlays, Federal R&D outlays have actually grown in recent years, from a level of 12 percent in 1980 to 14 percent in 1983. (See figure 2-12.)

Federal Influence on Private Sector R&D Investment

The Federal program for economic recovery has emphasized the goals of fostering innovation, increasing productivity, and stimulating the recovery of our economy.[22] Research and development thus assume an increasingly critical role, since investment in R&D programs is a key factor in the technological change that underlies productivity growth.[23]

The Federal Government can influence the rate of industrial innovation in several ways. This administration is focusing primarily on creating an economic climate conducive to increased private sector R&D investment. This includes changing Federal tax policies to provide incentives for R&D investment, liberalizing patent policies to facilitate technology transfer, and eliminating regulatory requirements that divert industrial resources from long-term innovation investments to short-term efforts that introduce changes mandated by law.[24]

Another way in which the Federal Government may stimulate private sector R&D activities is through its own patterns of support for research and development. For example, present Federal policies for sustained economic recovery include reductions in commercially oriented nondefense development support in favor of longer term R&D support in areas in which the private sector may not have the economic incentive to provide adequately for national interests, such as basic research.[25] Several studies of major R&D intensive expenditures have found a relationship between trends in Federal R&D spending and private sector R&D investment. Private R&D expenditures in one study increased by 6 cents per year for each Federal dollar in each of the first 2 years following an increase in Federal R&D spending, and decreased by 25 cents for each Federal dollar for the 2 years following a decline in Federal support; other studies have corroborated these results.[26]

As figure 2-13 reveals, there appears to be a positive relationship between the size and direction of annual changes in Federal R&D expenditures between 1967 and 1981, and subsequent growth and decline in private sector R&D investments.[27] General economic conditions may account, of course, for the observed relationship. The emergence of a possible relationship between Federal and private R&D funding patterns suggests, however, that Federal R&D funding decisions may also serve as a means of creating a climate conducive to additional private sector R&D investment, thereby facilitating economic recovery through yet another channel.

Functional Areas of Federal R&D Funding

The Office of Management and Budget (OMB) divides the Federal budget into function categories that reflect areas of Federal responsibility.[28] Of the 16 function cate-

[20] See ref. 16, pp. 3-5, and ref. 15, pp. 5-128 through 5-133.

[21] Outlays are considered relatively uncontrollable when the program level is determined by existing statutes or by contracts and other obligations. Medicaid and social security beneficiaries, for example, are eligible by law for Federal support. See ref. 15, pp. 6-31, and ref. 30.

[22] See ref. 8, and ref. 44, pp. 77-95.

[23] See ref. 17, pp. 4-7, ref. 43, pp. M-13 and M-14, and ref. 44, p. 77.

[24] See, for example, refs. 18, 20, 40, 41, 42, 47 and 51.

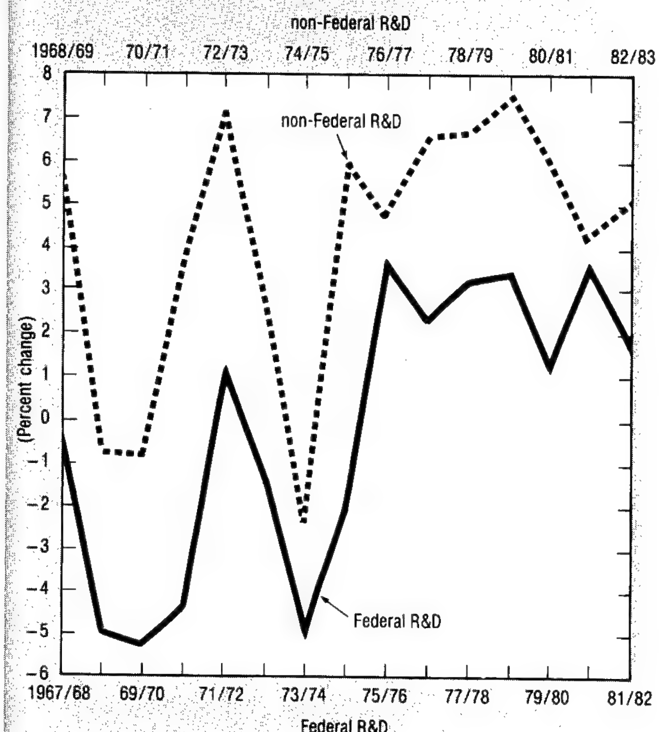
[25] See ref. 39.

[26] See ref. 22. Estimates vary widely with respect to the amount of change in private industry R&D expenditures associated with changes in Government R&D. See, for example, refs. 19, 21, 23, and 46.

[27] "Private sector" includes R&D funding provided by industry, academia, and nonprofit institutions. When differences in annual R&D budget levels for the Federal and private sectors are analyzed for the period 1967 through 1982, and private sector R&D investment changes lagged one year, there is a significant, positive correlation (r=0.87). This suggests that Federal R&D spending during that period accounts for 75 percent of the variance in private sector R&D investment one year later, although there may be some change in this relationship after 1979.

[28] Two of the 17 budget functions have no R&D components. For purposes of analyzing R&D support patterns, the budget function "general science, space and technology" has been divided into two separate categories, "space research and technology" and "general science," thus yielding 16 categories for analysis.

Figure 2-13
Relative annual percent change in constant dollars¹ for Federal and non-Federal R&D expenditures, by source



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
Based on appendix table 2-3.
Science Indicators—1982

gories that contain R&D programs, national defense receives by far the largest share of Federal R&D support. Preliminary estimates for fiscal year 1984 suggest that national defense will account for 70 percent of total Federal R&D budget authority. Health research and development is likely to account for about 10 percent of all Federal R&D budget authority, energy R&D almost 5 percent, and space research and technology just over 4 percent, while the sum total of the 12 remaining budget categories accounts for approximately 11 percent.

National Defense. The administration has placed greater emphasis on strengthening the Nation's defense capabilities. Since science and technology are central to the evolution of weapons and military systems in modern times, the renewed importance of national security has translated into significantly greater support for defense research and development.[29]

The R&D activities within this budget function largely represent the programs of DOD, although about 6 percent of the funds include atomic energy defense R&D activities of the Department of Energy.

Defense research and development has been the leading area of Federal R&D support since World War II.[30] As R&D programs in other areas were added over the years, the share of defense within the R&D total changed. While Federal funding for defense R&D grew from a level of $6 billion in 1960 to $32 billion in 1984 (see figure 2-14), defense R&D funding declined in constant-dollar terms between 1968 and 1975. By 1983, however, defense R&D activities are expected to reach a level of constant-dollar funding comparable to the 1967 peak year.

The proposal made in the 1984 budget to increase defense R&D to $32 billion in 1984—$7.1 billion over 1983 levels—reflects a substantial increase in strategic programs. These account for $3.3 billion of the $7.1 billion increase, and include, for example, R&D activities related to ballistic defense systems technology. Other areas in which defense R&D is expected to grow include: tactical programs, intelligence and communications programs, atomic energy defense R&D, and the defense technology base. The basic research component of the technology base program is proposed to increase by 10 percent between 1983 and 1984, with increased attention being given to human factors research.[31] For an example of recent funding trends in constant-dollar terms, see figure 2-15.

Health. The biomedical and clinical sciences have made significant contributions to the quality of life in the United States. As a result of the recent development of such powerful technologies as recombinant DNA techniques and hybridoma research, opportunities have emerged for further advancing human health through the production of new vaccines, for example, and the treatment of autoimmune disorders.[32]

Almost 90 percent of Federal health R&D funding supports biomedical research through the National Institutes of Health (NIH). The 11 separate Institutes are each expected to receive slight increases in 1984, varying from 1 to 3 percent.[33] Approximately 25 percent of the 1984 NIH budget is estimated to support the work of the National Cancer Institute. The $8 million (or 1 percent) increase over the 1983 budget would emphasize research on carcinogenesis, cancer control, and epidemiology, with decreased funding anticipated for clinical treatment research.[34] Over one-half of NIH's total 1984 R&D budget, or $2.1 billion, would support basic research, an increase of 1.8 percent over 1983 levels.

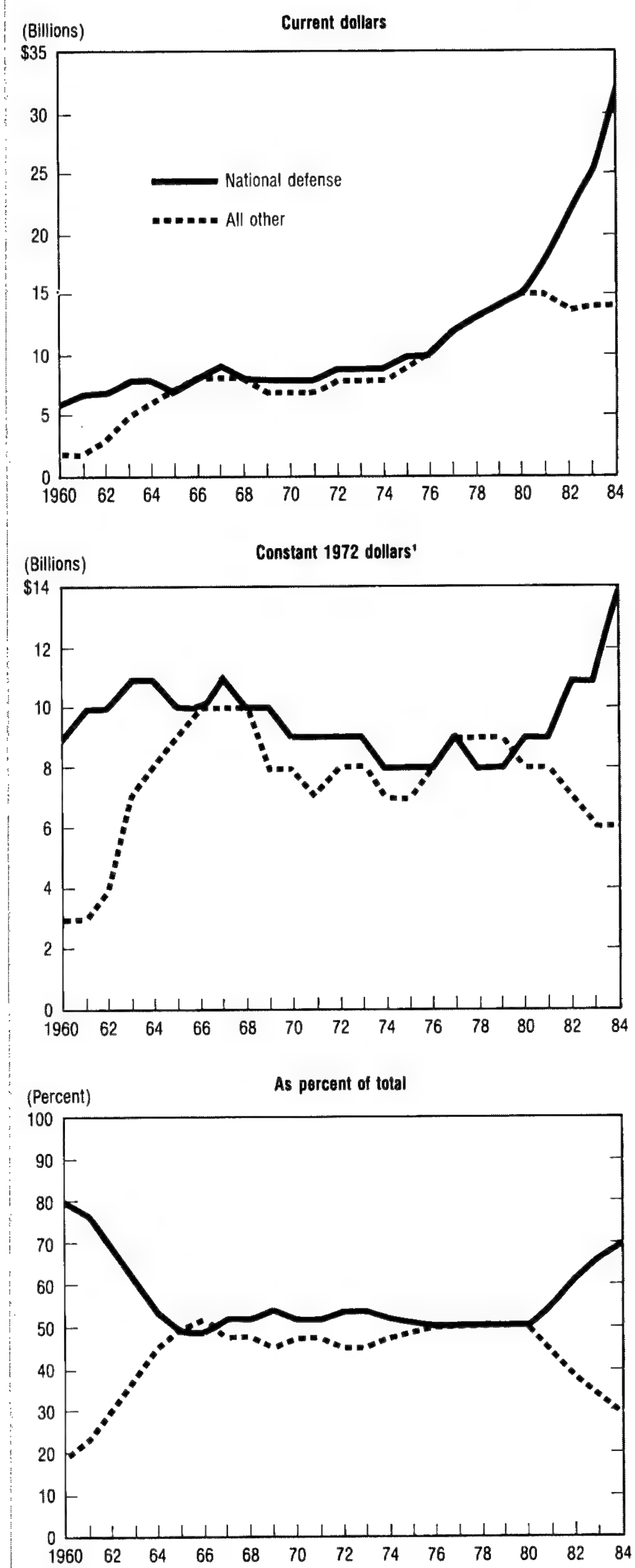
The Alcohol, Drug Abuse, and Mental Health Administration is expected to receive $314 million in 1984, 13 percent higher than the 1983 level. Substantial growth is expected in alcoholism research, which is estimated to reach $46 million in 1984, an increase of 38 percent over 1983 levels.

Energy. The 1973 oil embargo and subsequent rapid increase in the cost of imported oil stimulated greater Fed-

[29]See ref. 15, p. M-4, ref. 26, p. 469, and ref. 39, p. K-7.
[30]See ref. 25, p. 5.

[31]See ref. 39, p. K-7, and unpublished data. The realization of defense R&D program goals is also related, of course, to the ability of U.S. manufacturing industries to respond efficiently to military needs. Recent studies have suggested that greater emphasis be placed by Federal funding sources on procedures that would strengthen the manufacturing technology base, including greater incentives to increase company investment in modern equipment and facilities. See, for example, ref. 33.
[32]See ref. 7, volume 2, pp. 727-734, and refs. 48 and 29.
[33]See ref. 39, p. K-17, and ref. 49.
[34]*Ibid*.

Figure 2-14
Federal R&D budget authority for national defense



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1983 and 1984. Percentages calculated from unrounded data.
See appendix table 2-11.

Science Indicators—1982

eral investment in energy R&D.[35] Today, energy R&D represents almost 5 percent of total Federal R&D support, up from a level of just over 3 percent in 1971. (See appendix table 2-12.) In its peak year of funding (1980), however, energy R&D represented 12 percent of total Federal R&D spending.

Federal support for energy R&D programs is expected to total $2.3 billion in 1984, 11 percent less than the 1983 level. Energy R&D funding includes magnetic fusion development, where significant private investment is not likely without further Federal investment. In addition, the Federal energy program includes research on the environmental and human health effects of energy production technology.

Reductions in Federal support for energy R&D largely reflect the continued redirection of non-nuclear R&D programs, to limit Federal support to long-term generic research and to place greater reliance on the private sector for support of near-term technology development, especially in the areas of fossil fuel and solar energy demonstrations.

Space Research and Technology. Space research and technology (R&T) activities have provided valuable information about the earth and the universe. Space research and technology funding grew quickly from less than $400,000 in 1960 to more than $5 billion in 1966 as efforts were mounted to develop new launch vehicles and to advance technology in propulsion and spacecraft to the point where the results could be used in space flight programs.[36] As major developmental phases of the Apollo piloted lunar landing program[37] were completed, however, Federal obligations for space research and technology declined in absolute dollars between 1966 and 1974, and, consequently, as a share of total Federal R&D funds. After that time, Federal support for space research and technology continued to remain stable at a level of approximately $3 billion per year through 1980. Since 1980, Federal support for space research and technology has declined at an average annual rate of approximately 14.2 percent, reaching an estimated level of $1.9 billion in 1983. Between 1983 and 1984, the space R&T budget authority is expected to increase by $14 million, or 1 percent. (See appendix table 2-12.)

Recent reductions in space R&T funding are related in large part to the fact that the Space Shuttle program has entered its operational phase and thus is no longer classified as R&D. Budget figures for the space function from 1977 forward therefore exclude funding for Shuttle pro-

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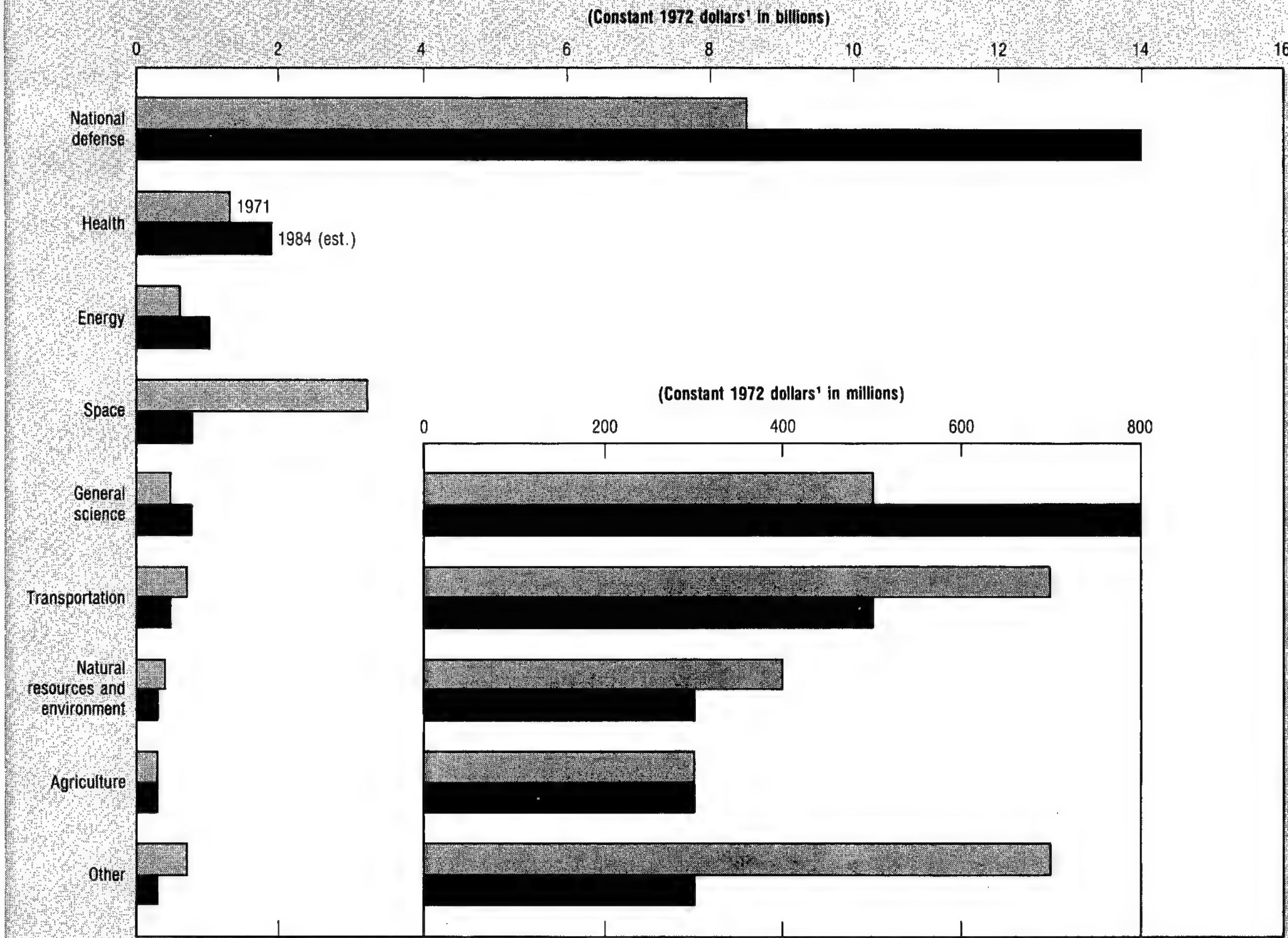
[35] See ref. 50.

[36] See ref. 24, p. 18. Federal support for aeronautics research laid much of the groundwork for space research and technology. As early as 1914, the National Advisory Committee for Aeronautics (NACA) was established by the Federal Government to conduct aerodynamics research. In 1958, with the formation of NASA, much of the responsibility for aeronautics research was shifted to DOD—although at significantly decreased levels—as NASA focused much of its attention on space activity. In the late 1960's, aeronautical research in NASA was strengthened as a result of Federal interest in aircraft noise problems, a growing concern with energy shortages, and recognized military requirements. Today, aeronautics research represents the vast majority of Federal support within the transportation budget function. See refs. 34, 36, and 37.

[37] See ref. 25, p. 6, and refs. 27 and 28.

Figure 2-15
Federal obligations for R&D by budget function in constant 1972 dollars[1]



[1]GNP implicit price deflators used to convert current to constant 1972 dollars.
NOTE: Data for 1971 are in the form of obligations and estimates for 1984 are budget authority figures.
See appendix table 2-12.

Science Indicators—1982

duction and operation, tracking and data acquisition activities, and related institutional support.[38]

Increases may be expected between 1983 and 1984 in basic research support (9 percent) and in space science (12 percent). By 1984, space science is estimated to represent more than half the total space R&T budget authority. This program studies the solar system and universe, using satellites in Earth orbit and spacecraft sent to planets and their moons. Major projects proposed for support in 1984 include the development of the space telescope, the Galileo mission to Jupiter scheduled for launching in 1986, advancement of the gamma ray observatory mission, and initiation of the Venus Radar mapping project scheduled for launching in 1988.

[38]See ref. 39, p. K-9.

Other R&D. Federal funds for R&D programs within the remaining budget functions rose steadily from a level of approximately $2.5 billion in 1971 to $5.1 billion in 1984. (See appendix table 2-12.)

Two factors contribute to current funding allocations in these areas: (1) a desire to eliminate or otherwise reduce Federal involvement in commercial technology demonstration projects, which are expensive and more appropriate for private sector support, and (2) a desire to realize fiscal savings by reducing support in those areas where programs have accomplished their intended mission or are no longer pertinent to Federal goals. The Federal Government became increasingly active, for example, in stimulating technological change in the civilian sector in the 1970's. Federal agencies supported demonstration projects in such areas as nuclear power reactors, personal rapid transit vehicles, and desalination plants in order to try to speed

up their introduction into commercial use.[39] There is no evidence of any long-term commercial success from these efforts.[40] Therefore, in addition to the curtailment of Federal support for energy demonstration projects, the 1984 Federal budget reflects similar decreases for geological hazard and mining development and demonstrations. Reductions are also anticipated in air transportation demonstration projects.[41]

Federal Support for Research

An important current issue is the impact of economic conditions on public and private support for research. While national expenditures for development—which represent two-thirds of all national R&D expenditures—are expected to grow by 4.9 percent in constant dollars between 1982 and 1983, national support for research will expand at a slightly lower rate of about 2.6 percent during that period once an adjustment for inflation has been made. (See appendix tables 2-6 and 2-9.)

About half the research conducted in the United States is supported by the Federal Government. Hence, decisions regarding the allocation of fiscal resources by that sector have a substantial impact on the magnitude and nature of research activities in this country. The relationship between Federal funding support and basic research is even more significant, because Federal support represents an estimated two-thirds of total national support for basic research.

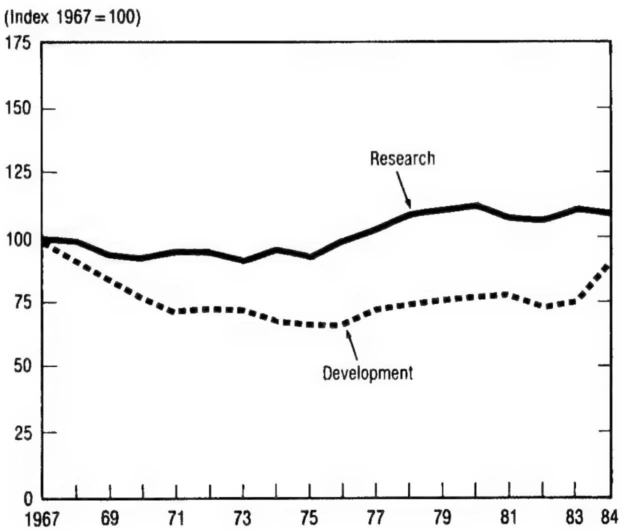
As figure 2-16 reveals, Federal obligations for research (basic and applied) grew at an average annual rate of about 1.0 percent in constant-dollar terms between 1967 and 1980. Between 1980 and 1982, Federal support declined at an average annual rate of 2.4 percent. Federal obligations for research are expected to rise at an average annual rate of 3.0 percent between 1982 and 1984 as the administration reallocates resources previously devoted to commercial demonstration projects for research, especially for basic research support. By 1984, Federal obligations for research should be about 13 percent higher in constant-dollar terms than they were in the 1967 peak year for R&D funding. Federal support for development declined at an average annual rate of about 4.6 percent in constant-dollar terms between 1967 and 1976. Although Federal obligations for development are expected to grow in constant dollars between 1976 and 1984 at an average annual rate of 4.2 percent, the level of support for development in 1984 is estimated to be about 8 percent less than the amount obligated in the previous peak year of 1967 (in constant dollars).

As shown in figure 2-17, Federal obligations for basic research have grown not only as a share of total Federal support for research, but also as a fraction of total Federal R&D obligations. In 1967, Federal obligations for basic research activities were estimated to represent 40 percent of Federal obligations for research and 11 percent of total R&D obligations. By 1984, basic research is expected to grow to represent 45 percent of total Federal research obligations and 15 percent of total Federal R&D obligations.

Three agencies are expected to account for about two-thirds of total Federal support for basic research in 1984:

Figure 2-16

Relative growth of Federal constant-dollar[1] obligations for research and for development



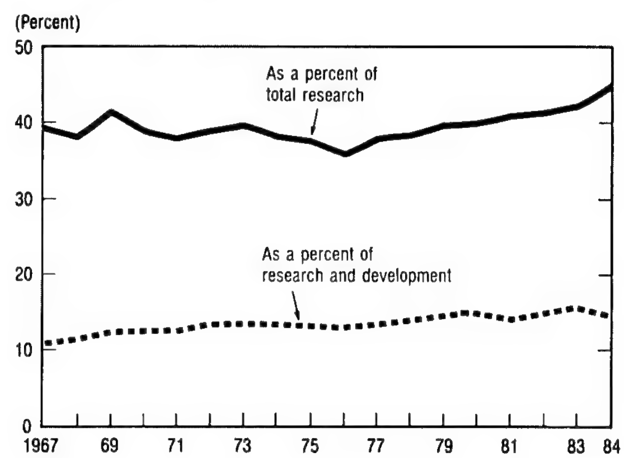
[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: Figures for 1982 through 1984 based on data supplied by the Office of Management and Budget from agency responses to OMB Exhibit 44. Data for all prior years drawn from National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1967-1983*, June 1982, p. 73.

Science Indicators—1982

Figure 2-17

Federal obligations for basic research as a percent of Federal obligations for research and for R&D



SOURCES: Figures for 1982 through 1984 based on data supplied by the Office of Management and Budget from agency responses to OMB Exhibit 44. Data for prior years drawn from National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1967-1983*, June 1982, p. 73.

Science Indicators—1982

[39]A study conducted in the mid-1970's concluded, for example, that nuclear power would not have become an available energy option without massive Federal R&D support at those critical times when reactor manufacturer support was being sought. See ref. 31, p. 33.

[40]See ref. 47, for example.

[41]See ref. 39, pp. K-22 through K-24, for example, and ref. 49.

DHHS, NSF, and DOE.[42] The largest share is provided by DHHS—about 34 percent of total Federal basic research support, most of which is provided by NIH. Between 1983 and 1984, basic research support is expected to grow by over 18 percent for both NSF and DOE; support provided by DHHS is expected to increase by less than 3 percent.

The life sciences and the physical sciences receive the greatest share of their Federal funds for basic research, 42 percent and 29 percent, respectively. (See figure 2-18.) As new Federal priorities have emerged, changes have occurred in the mix of fields receiving Federal basic research funding. (See table 2-1.)

Table 2-1. Percent distribution of Federal basic research obligations by major field of science

Field	Percent 1967	1980	1983
All S/E fields	100.0	100.0	100.0
Life sciences	38.3	44.0	42.1
Environmental sciences[1]	11.3	11.2	9.7
Physical sciences	32.3	26.1	28.6
Psychology	2.9	1.8	1.7
Mathematics and computer sciences	3.5	2.5	3.2
Engineering	8.3	10.0	11.4
Social sciences	3.0	3.2	2.2
Other sciences	.5	1.4	1.1

[1] Includes atmospheric sciences, geological sciences, oceanography, and other environmental sciences.

See appendix table 2-14.

Science Indicators—1982

The academic sector continues to account for the largest share of Federal obligations for basic research. (See figure 2-19.) The anticipated growth between 1982 and 1983 in Federal obligations for basic research is expected to result, however, in greater gains in the industrial performance of basic research relative to the growth of academic-based basic research (19 percent and 5 percent, respectively). Nonetheless, nearly 48 percent of total Federal basic research obligations in 1983 will support research performed in the academic sector.

Federal Funds for R&D Plant

The Federal Government plays an important role in subsidizing the purchase of scientific instruments and facilities for the research community. Part of the funding is included—but not separately identified—in Federal support for research and development through grants and contracts. Estimates are available, however, for separately budgeted R&D plant support.[43]

In recent years, the majority of Federal funds for R&D plant represented equipment expenditures of the Department of Energy (DOE), mostly synthetic fuels demonstration plants.[44] R&D plant costs for DOE were estimated to reach a level of about $1.2 billion in 1982, accounting for approximately 80 percent of total Federal R&D plant outlays.

After growing at an average annual rate of 11.6 percent between 1972 and 1982, Federal outlays for R&D plant are expected to decline by 29 percent in 1983. (See figure 2-20.) The anticipated decline is related to the reductions in the funding of facilities related to the demonstration of energy technologies. In 1983, support is expected to be maintained primarily for basic research facilities, such as those required for high-energy physics research.[45] Federal outlays for R&D plant are expected to continue to decline in 1984 as greater emphasis is placed on the acquisition of modern research equipment and instrumentation through R&D funding.[46]

As a percentage of total Federal R&D plus R&D plant outlays, Federal outlays for R&D plant are generally lower today than they were in the early 1960's. (See figure 2-21.) After climbing to a level of nearly 7 percent of R&D and R&D plant outlays in 1965, Federal support for R&D plant is estimated to be less than 1 percent of total R&D and R&D plant outlays in 1983. (See appendix tables 2-10 and 2-14.)

In constant-dollar terms, Federal funds for R&D plant are expected to grow between 1982 and 1983 only in intramural laboratories. (See figure 2-22.) Sharp drops are expected in R&D plant support to industry and to university-affiliated FFRDC's, again reflecting declines in support for Federal demonstration projects.

In summary, recent reductions in Federal obligations for R&D plant support appear to be related, for the most part, to changes in the scope of Federal support for energy R&D, especially that carried out with DOE support. Federal support for R&D plant has fluctuated as a share of total Federal outlays for R&D and R&D plant, and today is estimated to represent less than 1 percent of that total.

[42]See ref. 39, p. K-6.

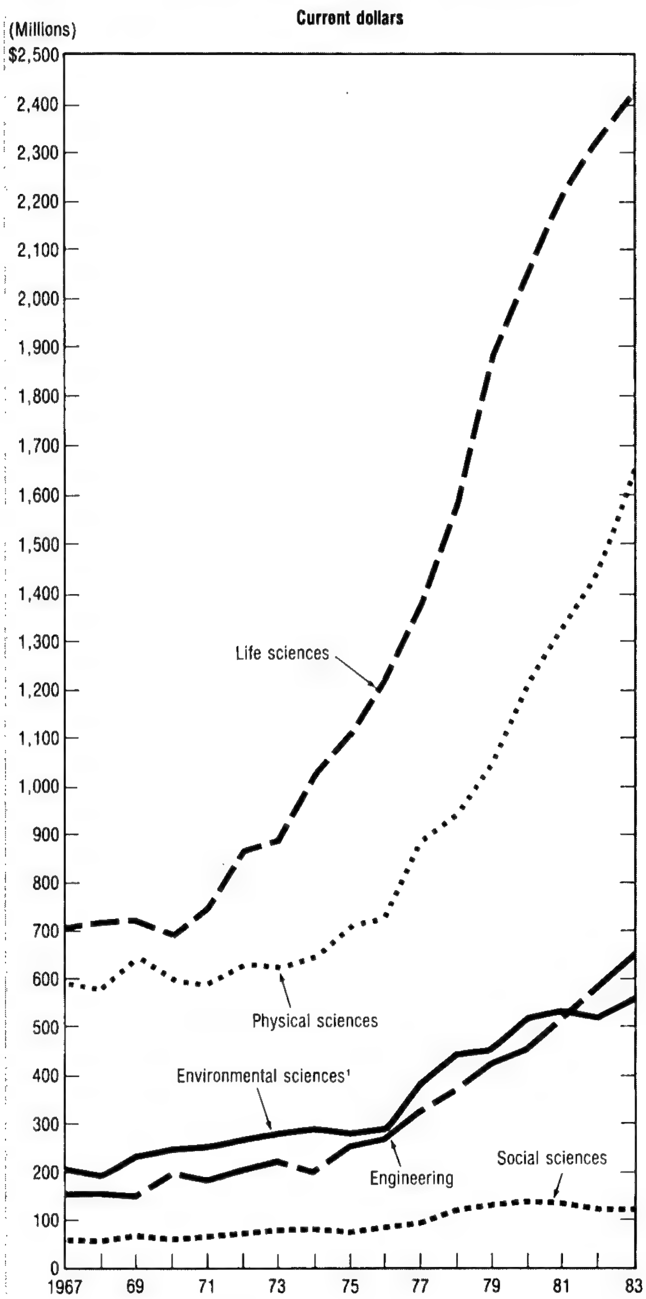
[43]Federal support for R&D plant includes funds for acquiring, constructing, repairing, or altering structures, equipment, facilities or land used in R&D activities at Federal or nonFederal installations. Excluded from the R&D plant category are expendable equipment and office furniture and equipment. R&D plant data are to some extent underreported because of the difficulty encountered by some agencies in identifying and reporting these data. While DOD, for example, reports obligations for R&D plant under the construction appropriation, DOD is able to identify only a small portion of the R&D plant support within R&D contracts that are funded from the RDT&E appropriation. Similarly, NASA cannot separately identify those portions of industrial R&D contracts applicable to R&D plant but subsumes R&D plant data in the R&D data covering industrial performance; R&D plant data for other performing sectors can be and are reported by NASA. See ref. 38.

[44]See ref. 11, pp. 7-8.

[45]*Ibid.*

[46]See ref. 39, p. K-6. Further analysis of the trends in scientific instrumentation and facility needs in the academic sector are provided in chapter 5 of this report.

Figure 2-18
Federal obligations for basic research by selected field of science

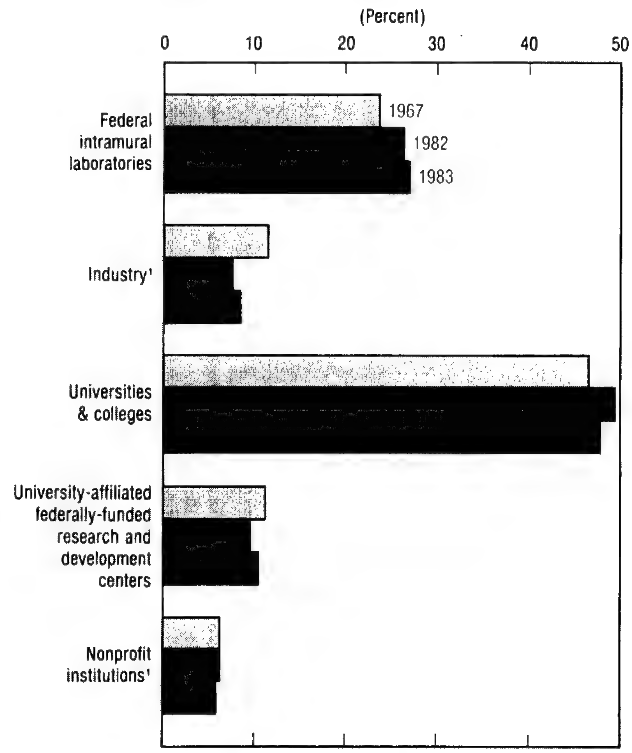


[1]Includes atmospheric sciences, geological sciences and oceanography.
NOTE: Estimates are shown for 1982 and 1983.
See appendix tables 2-14.
Science Indicators—1982

OVERVIEW

National support for research and development continues to increase in the United States as science and technology are called upon to help stimulate the American economy and to strengthen national defense capabilities. By 1983, total national R&D spending is expected to reach historically high levels of $87 billion. Even in constant-dollar terms, total national R&D spending in 1983—$39.7 billion—represents the highest levels ever.

Figure 2-19
Distribution of Federal basic research obligations by performer



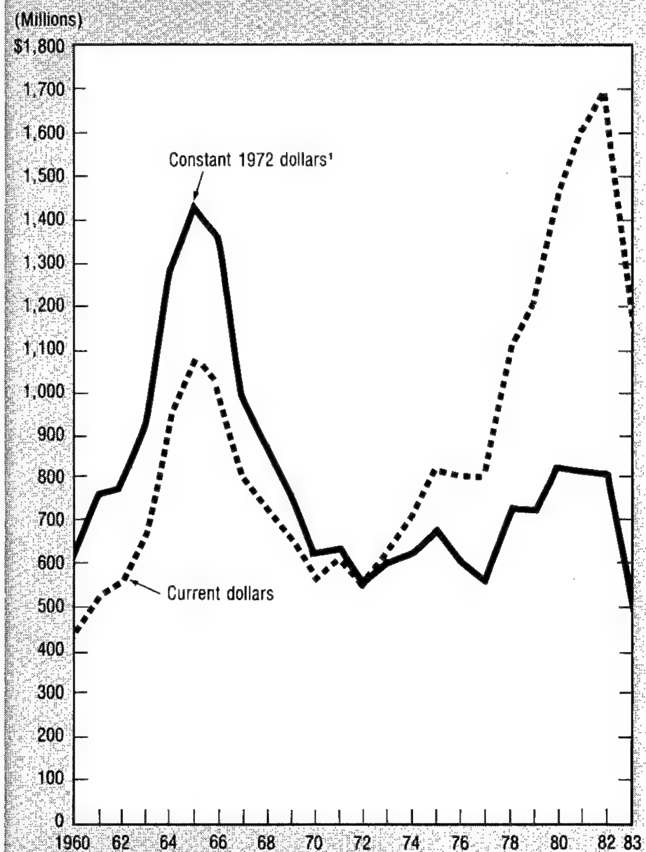
[1]Includes federally funded research and development centers (FFRDCs) administered in these sectors.
SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables, 1967-83*, June 1982, pp. 194-195.
Science Indicators—1982

In 1980, for the first time in two decades, the industrial sector spent more on research and development than did the Federal Government. Furthermore, between 1980 and 1983, industrial R&D support grew at an estimated average annual rate of 5.4 percent in constant dollars, compared with an average annual growth rate of 3.1 percent for Federal support. The increase in national investment in R&D activities in recent years is significant considering the fact that the GNP has been declining or growing at a slower rate than national R&D spending.

Real growth is expected in the research and development activities carried out by the industrial sector and by Federal intramural laboratories. R&D expenditures for these two performers together are estimated to increase at an average annual rate of about 4 percent between 1980 and 1983, in constant-dollar terms. A slight reduction is expected, however, in academic R&D between 1980 and 1983 (less than 1 percent in constant dollars), with more major reductions projected for R&D activities carried out in university-affiliated FFRDC's and other nonprofit institutions during that period.

Little change is expected in the distribution of national R&D expenditures between research and development. Development, which accounts for nearly two-thirds of total U.S. R&D spending, is expected to grow by about

Figure 2-20
Federal outlays for R&D plant



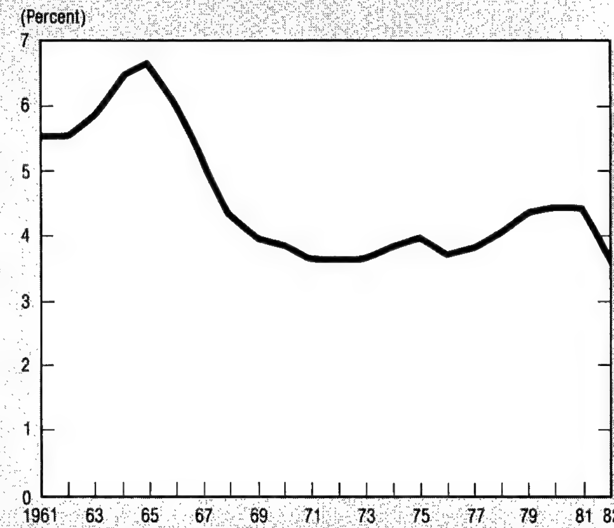
¹GNP fiscal year implicit price deflators used to convert dollars to constant 1972 dollars.
Note: Estimates are shown for 1982 and 1983.
See appendix table 2-15. Science Indicators—1982

5 percent between 1982 and 1983 in constant-dollar terms. National support for research is estimated to expand by about 3 percent between 1982 and 1983 in constant dollars, with significant expansion in industrial support for research accounting for most of that growth.

Federal investment in research and development continues to increase. As a proportion of controllable outlays, Federal outlays for R&D and R&D plant grew from a level of 12 percent in 1980 to an estimated level of 14 percent in 1983. Federal funding trends have resulted chiefly in expanded support for defense-related R&D.

Concerned with national economic recovery, the Federal Government has not only increased R&D support in selected budget areas, but has also focused on ways to stimulate private sector R&D investment. These include changing Federal tax policies to provide incentives for R&D investment, liberalizing patent policies to facilitate technology transfer, and reducing regulatory requirements. An analysis of annual changes in Federal and private sector R&D spending decisions shows that Federal R&D funding trends between 1967 and 1981 correlate strongly with private sector R&D spending decisions occurring 1 year later. This suggests that Federal R&D funding decisions may also serve as a means of stimulating subsequent additional private sector R&D investment.

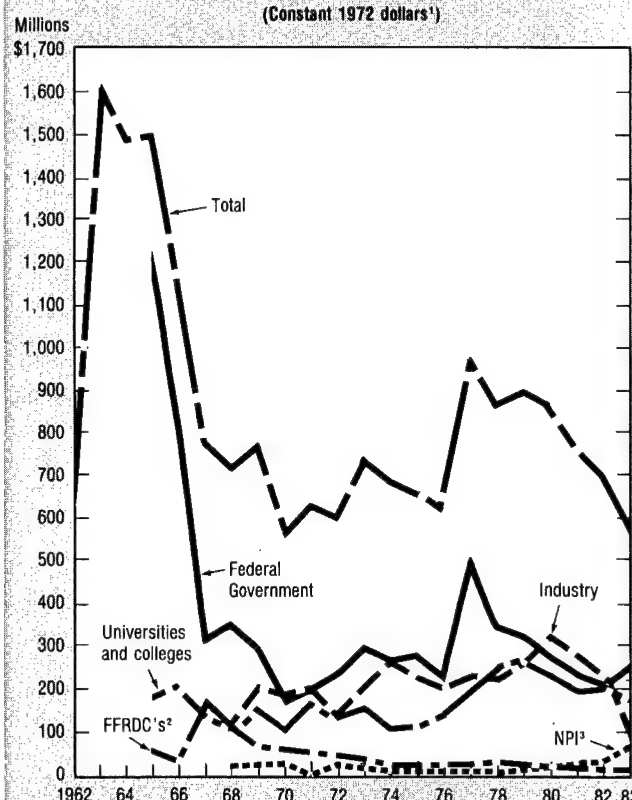
Figure 2-21
Federal outlays for R&D plant as a percent of total Federal outlays for R&D and R&D plant



Note: These data are three-year running averages to smooth out sharp year-to-year changes.
Based on appendix tables 2-10 and 2-15. Science Indicators—1982

Figure 2-22
Federal obligations for R&D plant by performer

(Constant 1972 dollars¹)



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Federally funded research and development centers administered by universities.
³Nonprofit institutions.
See appendix table 2-16. Science Indicators—1982

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Chapter 3
Science and Engineering Personnel

Science and Engineering Personnel

HIGHLIGHTS

- Labor market indicators suggest a pattern of shortages of computer specialists and, to a lesser extent, of engineers. However, preliminary 1982 data imply that there is movement toward a rough balance between supply and demand of engineers in general. There may still be shortages in particular fields of engineering. The indicators also show adequate supplies of environmental and physical scientists, psychologists, and social scientists, as well as a rough balance in the supply and demand for life and mathematical scientists. (See pp. 70-72.)

- Almost all S/E's who want jobs are employed. However, some hold jobs outside science or engineering. The proportion working outside science or engineering varies from almost 20 percent of the social scientists to about 6 percent of the computer specialists. The majority of those holding non-S/E jobs do so for voluntary reasons such as higher pay or better promotional opportunities. (See p. 63.)

- Employment in science and engineering (S/E) jobs reached 2.8 million in 1981, representing an increase of almost 6 percent per year since 1976. Over this period, employment of scientists grew at a faster rate than that of engineers (7.5 percent per year vs. 4.2 percent). Growth in engineering employment was affected by supply constraints. The rapid increases in scientific employment were paced by computer specialists, who accounted for about one-half of the total increase in scientific jobs. (See pp. 63-64.)

- Employment in S/E jobs accelerated between 1980 and 1981, and grew at a substantially faster rate (7.8 percent) than total U.S. employment (1.1 percent), employment of all professional and related workers (2.8 percent), and overall economic activity (2.0 percent), indicating shifts in national activity patterns toward those relating to science and technology. (See p. 64.)

- Industry's share of total S/E employment has been increasing slightly since the mid-1970's as has the proportion of all S/E's working in production and related activities. The shift to production and related activities, including quality control, reflects industry's rising commitment to improving productivity and increasing the international competitiveness of U.S. firms. (See pp. 65-67.)

- Although women scientists and engineers are still underrepresented, their employment increased at a much faster rate than employment of men S/E's (96 percent vs. 29 percent) between 1976 and 1981. Women represented about 13 percent of the 3.1 million S/E's employed in 1981, but were about 45 percent of all employed professional and related workers. (See pp. 67-68.)

- Blacks are underrepresented in science and engineering, while Asians are not. About 7 percent of those in professional and related jobs, but only about 2 percent of the S/E work force, are black. However, there has been some improvement in their representation. Employment of both black and Asian scientists and engineers increased more rapidly than the employment of white S/E's over the 1976-1981 period. The 64,000 black S/E's employed in 1981 represented a growth of over 85 percent since 1976. The comparable increase for Asians was almost 50 percent (from 56,000 to 83,000), while employment of white S/E's was up 34 percent. (See pp. 68-70.)

- Persons of Hispanic origin are underrepresented in the doctoral S/E work force. Although over 5 percent of all employed persons claimed Hispanic origins in 1981, only about 1.4 percent of all employed doctoral S/E's reported Hispanic origins for the same year. (See pp. 69-70.)

- At all degree levels, the number of degrees awarded in engineering and computer science rose rapidly while the number earning science degrees either declined or remained relatively stable. The number of S/E bachelor's degrees awarded in 1981 was about 3 percent below the peak year of 1974 while S/E master's degrees were about 3 percent below 1977 levels and S/E doctorates awarded were 7 percent below their peak year of 1973. (See pp. 77-80.)

- A strong background in mathematics and science is required for access to postsecondary educational opportunities in science and engineering. However, reductions in high school mathematics and science coursework required and taken, and scores on various standardized tests document the declining state of precollege mathematics and science education. A significant number of children at all ages are deficient in their ability to apply mathematical skills to solve problems. (See pp. 74-76.)

- Scores on both the verbal and mathematics parts of the Scholastic Aptitude Test (SAT) declined over the 1970's. However, this trend does not hold true for the scores of college-bound seniors planning to major in science and engineering. Average mathematics scores are generally higher for those planning to study engineering or the natural sciences than for those planning other areas of study. (See pp. 76-77.)

Scientists and engineers[1] play important and pervasive roles in almost every aspect of modern life, and they are one of the key factors in the status and progress of science and technology. Scientists and engineers conduct basic research to advance the understanding of nature, perform research and development in a variety of areas such as health and national defense, and train the Nation's future scientists and engineers. In addition, scientists and engineers play a vital role in ongoing efforts to improve the technological performance of U.S. industry in areas such as product innovation, quality control, and productivity enhancement.

This chapter starts with a review of recent utilization (employment) patterns of scientists and engineers and assesses the balance between current supply and demand. The roles and progress of women and racial minorities are also examined. The focus of the chapter then switches to an examination of the science and engineering "pipeline" which extends from precollege mathematics and science preparation to the school-to-work transition of recent science and engineering graduates.

UTILIZATION AND SUPPLY OF SCIENTISTS AND ENGINEERS

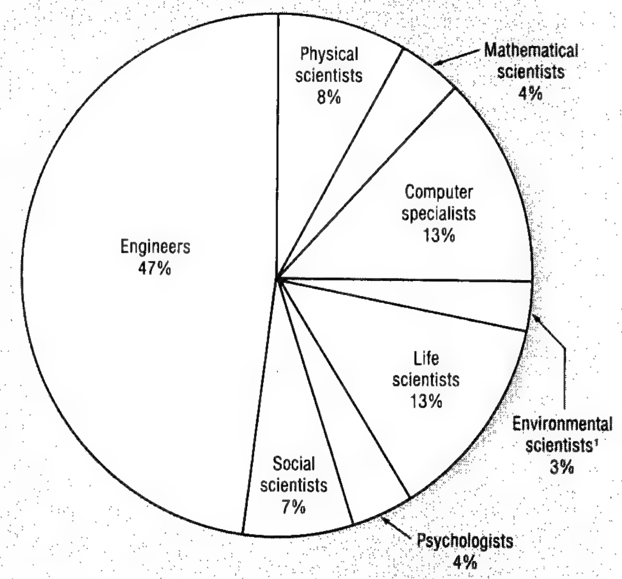
The indicators presented below show that employment of those in science and engineering jobs has grown more rapidly in recent years than total U.S. employment and overall economic activity, showing shifts in national activity patterns toward those related to science and technology. This increase has been very rapid for computer specialists and relatively slow for engineers because of a lack of qualified applicants for available jobs, although the situation for engineers appears to have changed in 1982. Employment opportunities for scientists and engineers have shifted slightly toward the industrial sector and away from educational institutions and the Federal Government.

The indicators also demonstrate that employment of women and racial minorities in science and engineering has increased more rapidly than employment of men and white S/E's. Despite this trend, women and racial minorities continue to be underrepresented in science and engineering.

Finally, the indicators reveal a pattern of shortages of computer specialists and, to a lesser extent, engineers. Preliminary 1982 data, however, suggest that supply and demand conditions for engineers, in general, may be moving away from a shortage situation, although there still may be shortages in some fields of engineering. Supplies of environmental and physical scientists, psychologists, and social scientists are more than adequate, with supply and demand for life and mathematical scientists in rough balance.

Almost one-half of the human resources devoted to science and technology in 1981 were in engineering. (See figure 3-1.) It is useful to distinguish between those who,

Figure 3-1
Employed scientists and engineers by field: 1981



¹Includes earth scientists, oceanographers, and atmospheric scientists.
NOTE: The total number of scientists and engineers in 1981 was 3.1 million.
Based on appendix table 3-3. Science Indicators—1982

on the basis of their education and experience, are scientists and engineers (S/E's) and the actual employment of those S/E's in science and engineering jobs. Trends in the latter reflect more directly the human resources active in the development of U.S. science and technology. Of the 3.1 million full- and part-time S/E's working in 1981, almost 90 percent held science or engineering jobs, about the same proportion as in 1976. By field, the proportion in S/E jobs ranged from almost all computer specialists to about 80 percent of the social scientists. (See figure 3-2.) Those holding S/E doctorates are slightly more likely than others to have jobs in science or engineering.

Employment of scientists and engineers in non-S/E jobs does not necessarily mean that they are being underutilized from a societal perspective. Most S/E's who choose to work in non-S/E positions do so for higher pay, better promotional opportunities, or other personal reasons, such as preference for a particular location.[2]

Employment in Science and Engineering

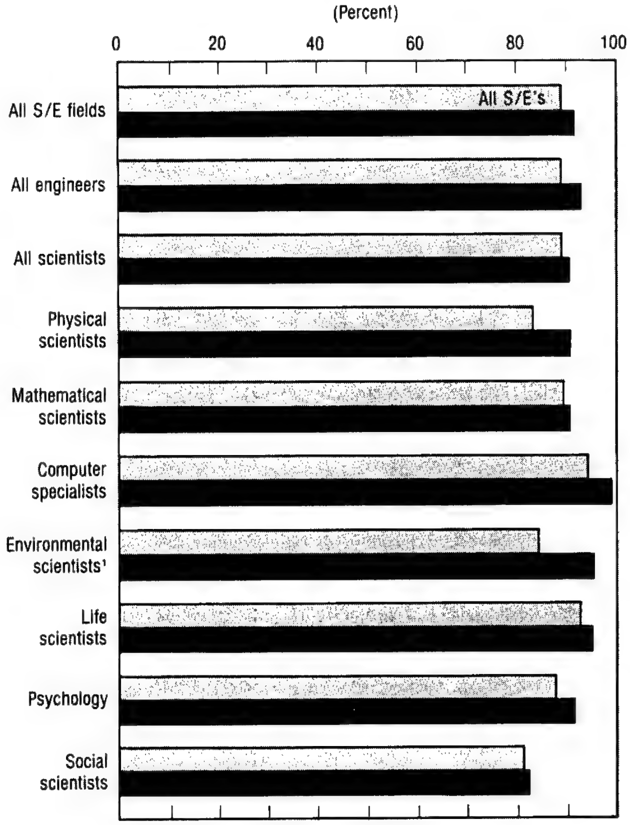
A principal indicator of the level of U.S. science and technology activity is the number of individuals employed in science and engineering work (ES/E's).[3] If employment in science and engineering increases more rapidly than total U.S. employment or other economic indicators, the comparison suggests that society is placing greater emphasis

[1]Broadly speaking, a person is considered a scientist or engineer if he or she holds his or her highest degree in a science (including social science) or engineering field and is either employed in a science or engineering job or professionally identifies himself or herself as a scientist or engineer based on total education and work experience.

[2]See ref. 1.

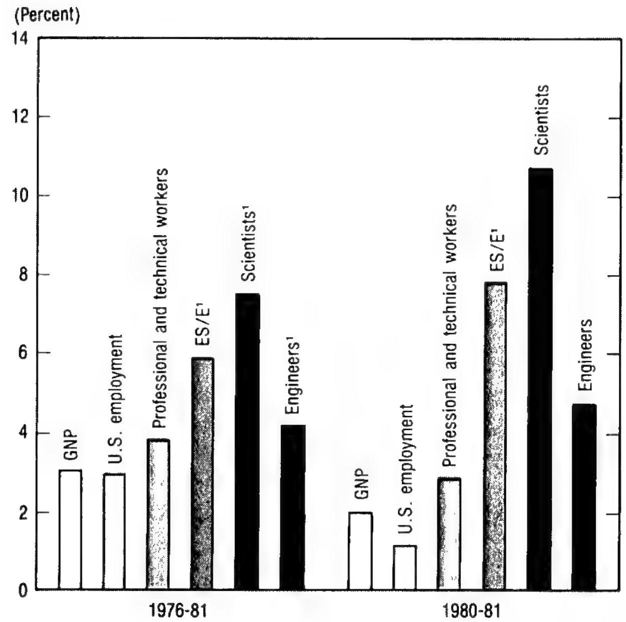
[3]E/SE is used as an abbreviation for those scientists and engineers employed in science or engineering jobs.

Figure 3-2
Percent of employed S/E's in science and engineering jobs: 1981



[1]Includes earth scientists, oceanographers, and atmospheric scientists.
Based on appendix tables 3-3 and 3-6. Science Indicators—1982

Figure 3-3
Average annual growth in ES/E employment and other manpower and economic variables



[1]Those in science or engineering jobs.
See appendix table 3-7. Science Indicators—1982

on technical rather than nontechnical activities. Recent emphasis on increasing defense expenditures, levels of research and development expenditures, and efforts to increase the competitiveness of U.S. industries suggests that science and engineering employment would be expected to grow at a faster rate than overall U.S. employment. This expectation is confirmed by the data.

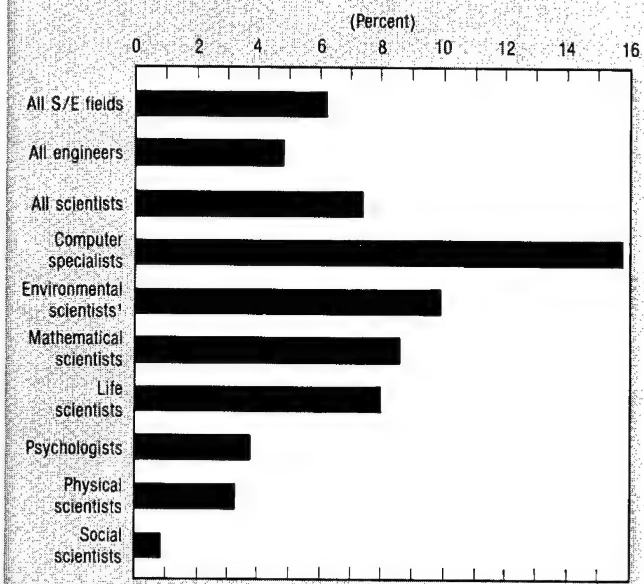
Between 1976 and 1981, the number of ES/E's expanded at a substantially faster rate than did total employment, employment of all professional and related workers, and overall economic activity. ES/E employment increased at an average annual rate of 5.9 percent (7.5 percent for scientists and 4.6 percent for engineers) over the 1976-1981 period, reaching 2.8 million. (See figure 3-3.) In the same period, total U.S. employment and employment of all professional and related workers increased at annual rates of 2.9 percent and 3.8 percent, respectively. In addition, real gross national product (GNP)—an indicator of overall economic activity—increased at an average annual rate of 3.0 percent. Between 1980 and 1981, employment growth for scientists and engineers accelerated while the increases in GNP and other employment indicators slowed considerably.

Growth in employment of scientists and engineers (both in S/E and other jobs) between 1976 and 1981 varied substantially among fields. (See figure 3-4.) In science occupations, the average annual rate was 7.4 percent, reaching almost 1.7 million by 1981. If computer specialists are excluded from the analysis, the annual average rate for scientists drops to 5.3 percent and employment drops to slightly over 1.2 million. In engineering jobs, the average annual rate of increase was 4.8 percent, reaching about 1.5 million by 1981. Although engineering employment growth varied by field, it was not as great as that among science fields. (See figures 3-4 and 3-5.) Growth in engineering employment was inhibited by supply constraints in the late 1970's and early 1980's.

Computer specialists and mathematical, environmental, and life scientists showed increases in employment above the average for all scientists. Computer specialists alone accounted for almost 45 percent of the total growth in scientific employment over the 1976-1981 period. The large increase since 1976 in the employment of computer specialists raises the question of whether individuals without computer science degrees are employed as computer specialists. Degree distribution figures show that of the approximately 33,000 recent science or engineering baccalaureate graduates employed as computer specialists in 1980, only about 41 percent earned their bachelor's degrees in computer science. An additional 22 percent had mathematics degrees, while the remainder had degrees in the physical, life, and social sciences, and engineering. At advanced degree levels, the influx of mathematics degree recipients into computer science occupations shows a substantial decline, while engineering graduates show an increase.[4]

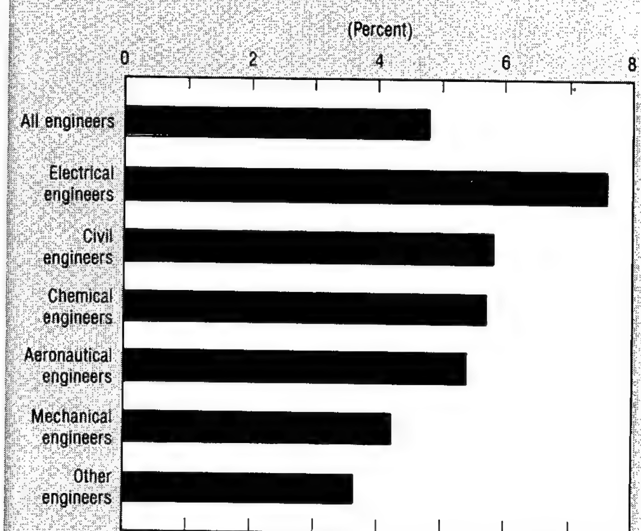
[4]See ref. 26, tables B-8, B-17, B-26, and B-35.

Figure 3-4
Average annual growth in number of all employed scientists and engineers by field: 1976-81



[1]Includes earth scientists, oceanographers, and atmospheric scientists.
Based on appendix table 3-2. Science Indicators—1982

Figure 3-5
Average annual growth in number of all employed engineers: 1976-81



Based on appendix table 3-3 and National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314). Science Indicators—1982

Science and Technology Activities

Data on work activities of scientists and engineers,[5] as measured by the number, proportion, and distribution of those doing research and development (R&D), teaching, and other activities, are a direct indicator of the character of the U.S. science and technology (S/T) enterprise. Sectoral employment patterns and changes in these patterns also indicate changes in the character of the S/T enterprise.[6]

In 1981, about 28 percent of all employed S/E's reported their primary work as R&D, and an additional 7 percent cited management of R&D as their primary activity. Thus, over one-third (35 percent) were involved in some aspect of R&D. (See figure 3-6.) Many S/E's are also involved in general management, production, and teaching, with the activities of scientists differing from those of engineers. The distribution of work activities has changed only slightly since the mid-1970's. (See appendix table 3-8.) However, even small changes in the patterns of primary work activities can mask sizable absolute shifts in employment changes. For example, the proportion of all S/E's engaged in production and related activities increased from about 12 percent to 14 percent, representing an absolute increase of over 150,000. Most of this increase was accounted for by engineers in industry, reflecting the added emphasis in industry on improving productivity and increasing the international competitiveness of U.S. companies.[7]

The number of S/E's primarily employed in R&D (excluding R&D management) increased at an average annual rate of 6.8 percent to over 870,000 between 1976 and 1981, substantially faster than the increase in all other activities combined (5.9 percent per year). The most recent data show a shift from research to development activities. Between 1980 and 1981, the number primarily working in research activities increased by 7.8 percent, while the number working in development activities increased by 9.4 percent. The increased emphasis on development rather than research reflects, in part, a similar change in Federal funding since 1980.[8]

Most employed scientists and engineers (60 percent or 1.9 million) worked in the business and industry sector in 1981. Since the mid-1970's, the share employed in business and industry has increased by about 5 percentage points while declining slightly for educational institutions and the Federal Government. (See figure 3-7.) The growing proportion of S/E's in industry reflects the relative concentration of S/E's in those industries (generally high technology) where overall employment is increasing rapidly, and changes are occurring in the skill mix of industrial employment. In many industries, the occupational mix is shifting away from those involving relatively low skill levels, such as laborers, to those involving relatively high skill levels such as engineers, computer specialists, and other scientists. The shift in employment away from educational institutions results primarily from demographic factors that are causing enrollment to grow more slowly and in some cases to decline, although salary levels may be a factor in some fields.

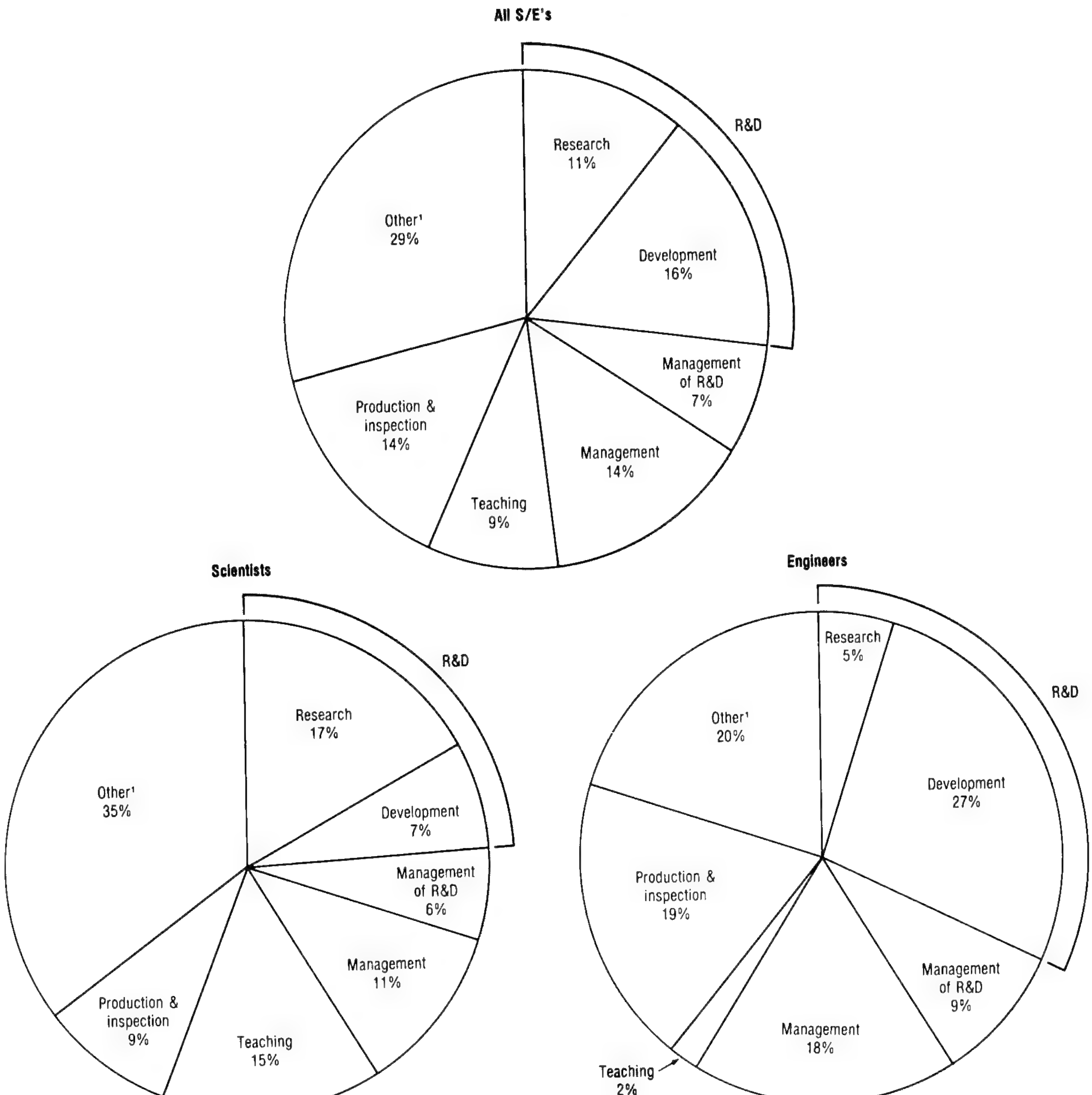
[5]All employed scientists and engineers, not just those in science or engineering jobs.

[6]See chapters on Academic Science and Engineering and on Industrial Science and Technology.

[7]See ref. 2.

[8]See ref. 3.

Figure 3-6
Distribution of scientists and engineers by primary work activity: 1981



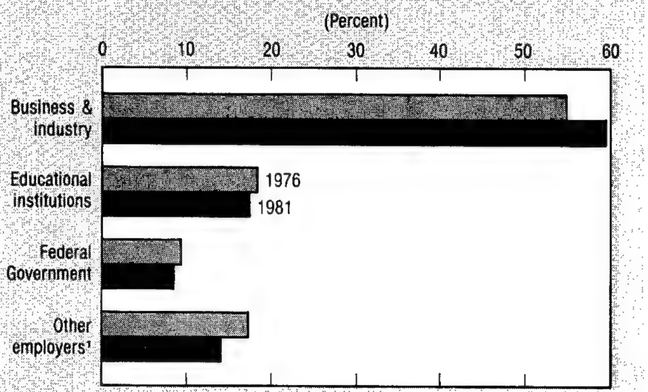
¹Includes reporting, statistical work and computing; consulting, other; and no report
Based on appendix table 3-8.

Science Indicators—1982

As expected, these sectoral shifts are more readily apparent among recent S/E graduates.[9] At the bachelor's level, 65 percent of the 1978 and 1979 graduates were employed in industry in 1980, and 9 percent were employed by educational institutions. In 1976, about 55 percent of the 1974 and 1975 S/E graduates found employment in business and industry, and 12 percent found employment in educational institutions. Changes at the master's level were even more pronounced. In 1980, 52 percent of the 1978 and 1979 graduates were working in business and industry, and 18 percent were in educational institutions. Comparable figures for 1976 showed 37 percent in business and industry and 24 percent in educational institutions. Among those receiving S/E doctorates (and who had employment plans) in 1981, about 45 percent planned to

[9]See ref. 4.

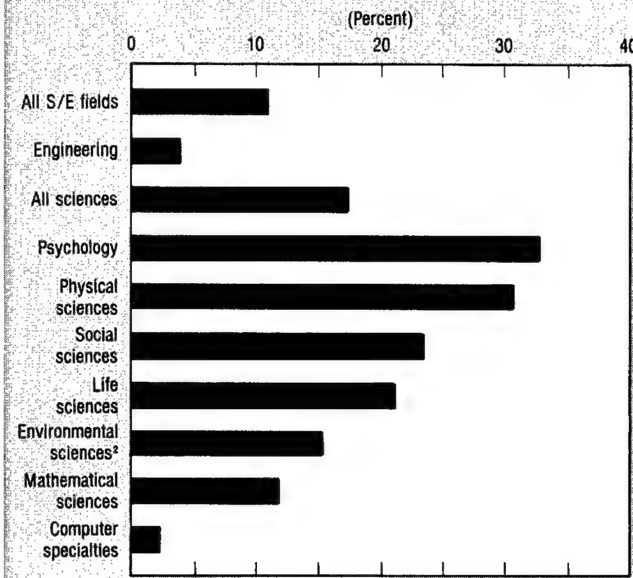
Figure 3-7
Distribution of scientists and engineers by sector of employment



¹Includes state, local and other government; nonprofit organizations; military; other and no report.

See appendix table 3-10. Science Indicators—1982

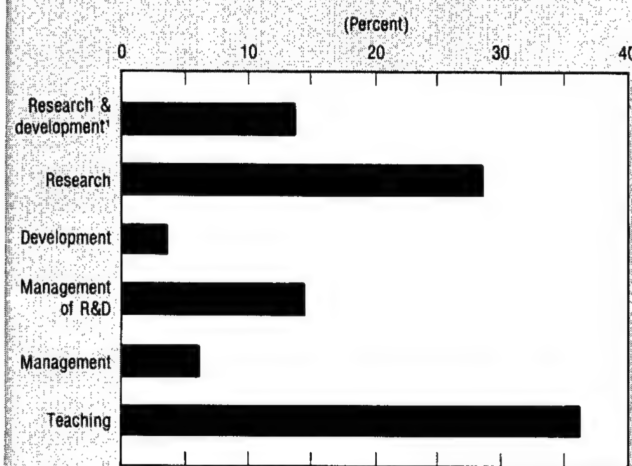
Figure 3-8
Doctoral intensity[1] of the S/E work force: 1981



¹The ratio of employed Ph.D. S/E's to total employed S/E's.
²Includes earth sciences, oceanography, and atmospheric sciences.

See appendix table 3-12. Science Indicators—1982

Figure 3-9
Doctoral intensity of the S/E work force for selected primary work activities: 1981



¹Excludes R&D management.

Based on appendix tables 3-8 and 3-9. Science Indicators—1982

work in educational institutions, down from about 55 percent in 1976. Conversely, about 30 percent of the 1981 graduates planned to work in industry, up from 20 percent in 1976.

Quality of the S/E Work Force

There has been increasing speculation about possible declines in the quality of the scientific and technical work force. Such questions are difficult to resolve because no direct measure of overall work force quality exists. However, the proportion of the S/E work force holding doctorates (i.e., "doctoral intensity") is an indicator of work force quality since doctoral level S/E's provide much of the leadership in scientific activities.

Scientists and engineers with doctorates are a relatively stable proportion of the work force. In 1981, about 11 percent of the employed S/E's held doctorates, about the same as in 1976. This proportion varies substantially by field, however, with scientists much more likely than engineers to hold such degrees. (See figure 3-8.) Excluding computer specialists, over 22 percent of the scientists held doctorates while 2 percent of the computer specialists and 4 percent of the engineers held such degrees. The relatively low doctoral intensity for computer specialists and engineers reflects the fact that the bachelor's degree is frequently the accepted level for entry into these fields. The doctoral intensity in some fields has shifted over time. Decreasing percentages were noted among mathematical (from 16 percent in 1976 to 12 percent in 1981), environmental (19 to 15 percent), and life scientists (25 to 21 percent); increases took place among psychologists (from 29 to 33 percent) and social scientists (from 18 to 23 percent). For physical scientists, engineers, and computer specialists, the figures remained stable. (See appendix table 3-12.)

The doctoral intensity of the S/E work force also differs by primary work activity. (See figure 3-9.) Between 1976 and 1981, the doctoral intensity in R&D activities remained relatively constant while declining slightly in teaching. The decline is related in part to the inability of educational institutions to attract and keep doctorate holders in some fields, such as engineering and computer sciences and to a desire on the part of some institutions to reduce costs by hiring those without doctorates.

Women in Science and Engineering

Although women scientists and engineers are still underrepresented, employment for this group increased at a much

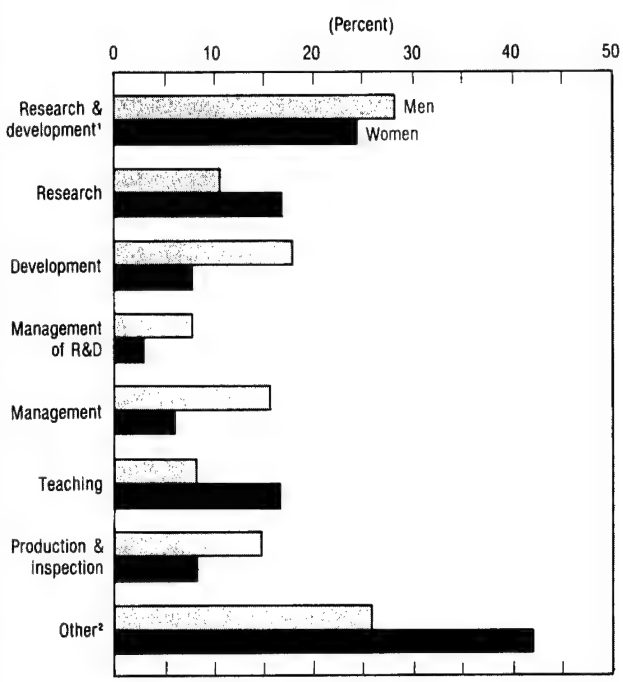
faster rate than for men S/E's (96 percent vs. 29 percent) between 1976 and 1981. Approximately 420,000 women scientists and engineers were employed in 1981, representing over 13 percent of the 3.1 million employed S/E's, up from 9 percent (214,000) in 1976.

The almost doubling of the employment of women S/E's was paced by an over 200 percent increase in the number of women computer specialists. Between 1976 and 1981, almost two-fifths of the increase in the employment of women S/E's was accounted for by increases in the number of women computer specialists. As a result of this very rapid increase, the proportion of all employed computer specialists who were women increased to 26 percent (110,500) in 1981, up from about 16 percent (33,200) in 1976.

Women are much more likely than men to be scientists rather than engineers. However, the number of women engineers tripled between 1976 and 1981, reaching almost 35,000. Despite this very rapid increase, only about 2 percent of all employed engineers were women. Among science fields, the proportions of women in psychology, social sciences, and computer specialties were much higher than in the other fields.

Partially reflecting differences in field distributions discussed above, especially the split between scientists and engineers, the work activities of women S/E's differed significantly from those of men S/E's in 1981. (See figure 3-10.) Although roughly similar proportions of both men and women are primarily engaged in R&D activities, women are more likely than men to be in research rather than development. Women S/E's are twice as likely as men S/E's to report teaching as their primary activity (16 percent vs. 8 percent), while men are more than twice as likely as women to be primarily engaged in management activities (24 percent vs. 9 percent).

Figure 3-10
Distribution of scientists and engineers by primary work activity and sex: 1981



[1]Excludes R&D management.

[2]Includes reporting, statistical work, and computing; consulting; other; and no report.

Based on appendix table 3-8. Science Indicators—1982

Employment of women holding doctorates in science or engineering also increased at a faster rate than men over the 1976-1981 period (65 percent vs. 23 percent). The 41,000 employed doctoral women S/E's in 1981 represented about 12 percent of all employed doctoral S/E's, up from around 9 percent in 1976.

In 1981, about 10 percent of both male and female S/E's held doctorates. If engineering—still a predominantly male field—is excluded from the analysis, the proportion of women scientists holding doctorates remains at about 10 percent, but the proportion of men S/E's with doctorates increases to 20 percent. Differences between the sexes in level of educational attainment vary significantly by field (see figure 3-11), with the largest differences in physical and social sciences and psychology.

Despite the rapid employment growth for women S/E's, women are still underrepresented in science and engineering, as opposed to the total U.S. labor force and all professional and related fields. In 1981, women represented about 43 percent of all employed persons and 45 percent of all professional and technical workers,[10] but only 13 percent ofall S/E's.

Minorities in Science and Engineering

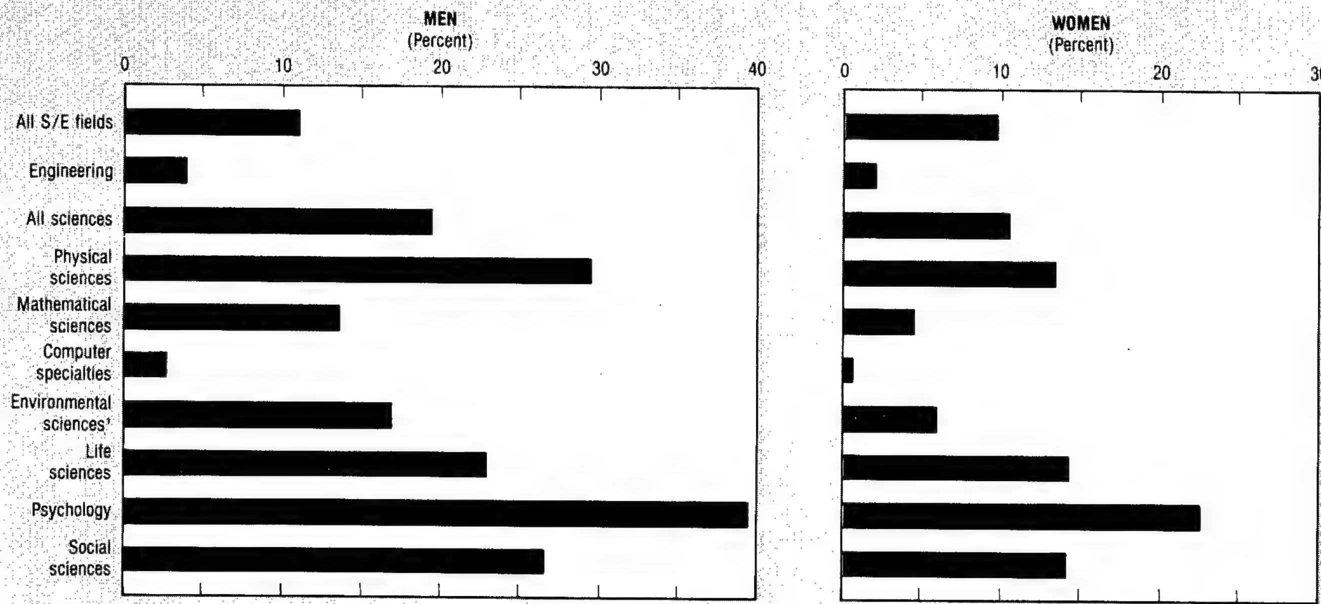
Employment of both black and Asian scientists and engineers increased more rapidly than the employment of white S/E's over the 1976-1981 period. The 64,000 black S/E's employed in 1981 represented a growth of over 85 percent since 1976. The comparable increase for Asians was almost 50 percent (from 56,200 to 83,500), while employment of white S/E's was up 34 percent. Despite these rapid increases, blacks represented about 2 percent of all employed S/E's in 1981, while Asians represented almost 3 percent.

Black, Asian, and white S/E's are concentrated in different fields. Blacks are less likely than whites to be engineers; almost half of the white S/E's but only about one-third of the blacks are engineers, and blacks represent only slightly over 1 percent of all employed engineers. (See figure 3-12.) In science, blacks are more likely than whites to be social or mathematical scientists. Asian S/Es have a somewhat higher concentration in the fields of engineering and the computer specialties and a lower concentration in psychology that either white or black S/E's. (See table 3-1.)

Although employment of blacks increased in all fields, almost three-fifths of the 30,000 increase in the number of employed black S/E's between 1976 and 1981 was accounted for by growth in only two fields—engineering (from 10,800 to 20,600) and computer specialties (from 2,800 to 10,200). Another 25 percent of the increase took place among social scientists (up from 3,500 in 1976 to 11,000 in 1981). As a result of these differential growth rates, the field distribution of black S/E's has changed somewhat over time, moving closer to that of whites.

[10]See ref. 5, p. 165.

Figure 3-11
Doctoral intensity of the S/E work force by sex: 1981



[1]Includes earth sciences, oceanography, and atmospheric sciences.
Based on appendix tables 3-2 and 3-4.

Science Indicators—1982

Table 3-1. Distribution of employed scientists and engineers by field and race: 1981

Field	Percent		
	White	Black	Asian
All S/E fields	100.0	100.0	100.0
Physical scientists	7.3	7.8	10.2
Mathematical scientists	4.1	8.1	4.9
Computer specialists	13.2	15.9	18.4
Environmental scientists[1]	3.4	.9	1.3
Engineers	47.5	32.1	50.1
Life scientists	13.2	12.9	11.3
Psychologists	4.3	5.3	.7
Social scientists	7.1	17.2	3.1

[1] Includes earth scientists, oceanographers, and atmospheric scientists.
REFERENCE: Based on appendix tables 3-13 and 3-14.

Science Indicators—1982

Among Asians, about 85 percent of the increase in employment between 1976 and 1981 took place among engineers (from 28,900 to 41,800) and computer specialists (from 5,000 to 15,400). The only major field in which employment of Asians declined was the social sciences.

Blacks are clearly underrepresented in science and engineering. Asians, who make up a smaller percentage of the population, are not. In 1981, blacks and other minorities represented 9 percent of all professional and related workers.[11] Of these minorities in professional and related jobs, over three-fourths were black. Thus, blacks represented about 7 percent of those in all professional and related jobs, but only about 2 percent of the entire S/E work force.

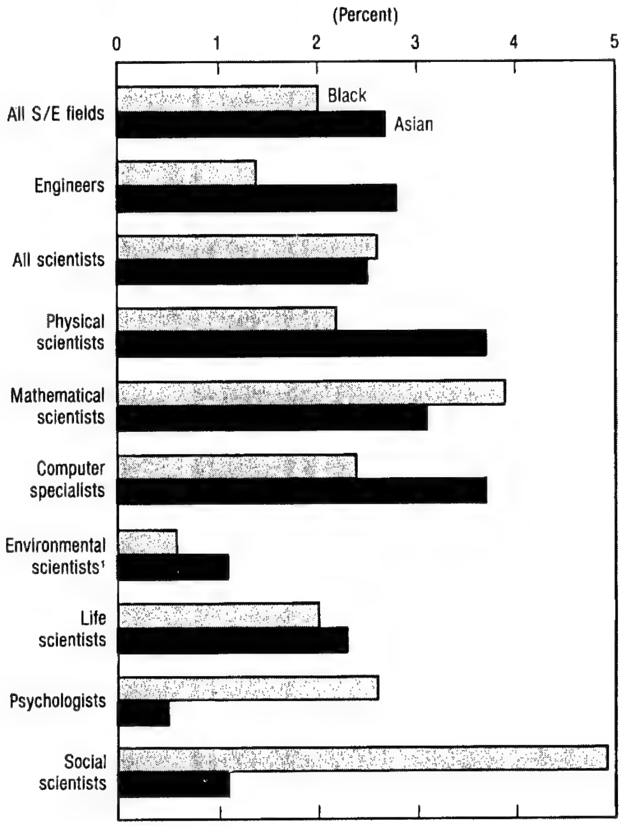
Employment of both blacks and Asians holding doctorates in science or engineering increased at a faster rate than that of whites with doctorates over the 1976-1981 period. The number of Asian S/E's holding doctorates increased by about 90 percent between 1976 and 1981; for blacks, the increase was 63 percent and for whites, 25 percent. In 1981, Asian S/E's had a higher level of educational attainment than their white or black colleagues. Almost one-third of Asian S/E's held doctorates in 1981, up from 25 percent in 1976. Among black S/E's, about 7 percent held doctorates in 1981, about the same proportion as in 1976. Employment of white S/E's with doctorates, however, did not keep pace with the overall increase in employment of whites. In 1981, about 10 percent of white S/E's held doctorates, down slightly from the estimated 11 percent in 1976.

Persons of Hispanic origin[12] are underrepresented in the doctoral science and engineering work force. Although over 5 percent of all employed persons 20 years of age and older claimed Hispanic origins and about 2.6 percent of all professional and related workers were Hispanic in 1981, the 4,800 Hispanic doctoral S/E's represented only about 1.4 percent of all employed doctoral S/E's for the

[11]See ref. 5.

[12]Hispanics are a diverse ethnic group and it would be desirable to distinguish among Mexican-Americans, Puerto Ricans, and other Hispanics. However, because of data constraints, Hispanics in this discussion must be treated as an aggregate and the discussion limited to Hispanic scientists and engineers holding doctorates. Efforts are currently underway by the National Science Foundation to improve and expand the data on Hispanic scientists and engineers.

Figure 3-12
Black and Asian S/E's as a proportion of all employed S/E's: 1981



[1]Includes earth scientists, oceanographers, and atmospheric scientists.
See appendix table 3-13. Science Indicators—1982

same year. The number of employed Hispanic doctoral S/E's has more than doubled since 1977, when the approximately 2,200 Hispanics represented less than one percent of all employed doctoral scientists and engineers.

Both Hispanic and non-Hispanic doctoral S/E's show roughly similar distributions by field. About 25 percent of each group were life scientists in 1981, and about 20 percent were physical scientists. On the other hand, Hispanics were somewhat more likely than their non-Hispanic colleagues to be social scientists or psychologists, and somewhat less likely to be engineers or environmental scientists.

LABOR MARKET INDICATORS

Statistics on employment of scientists and engineers alone do not indicate whether the current supply is sufficient to meet the needs of the economy. Recent concerns over shortages of engineers and computer specialists, and about suitable job opportunities for some scientists suggest a potential maldistribution in the labor market for S/E's and a need for indicators to assess supply and demand conditions. Standard labor market indicators of supply and demand conditions include labor force participation and unemployment rates and relative salaries. In addition, the S/E utilization rate helps assess both the market for science and engineering jobs and the extent to which those with training in science and engineering are utilizing their training. No single statistic can provide a firm basis for measuring shortages and surpluses of scientists and engineers. But some statistics, when examined together, permit inferences about the condition of the S/E labor market.

The indicators examined below reveal a pattern of shortages of computer specialists and, to a lesser degree, of engineers. However, preliminary 1982 data suggest that supply and demand for engineers is moving away from a shortage situation toward one of balance. The indicators also show more than adequate supplies of environmental and physical scientists, psychologists, and social scientists with the supply of life and mathematical scientists in rough balance with demand. The indicators only reveal the general supply and demand patterns for major S/E fields. Supply and demand conditions for particular fields or subfields may differ from conditions for the overall field. For example, a shortage of engineers does not indiate that all fields of engineering are in a shortage situation.

Labor Force Participation Rates

The S/E labor force includes scientists and engineers who are employed, either in or out of science and engineering, and those who are unemployed and seeking employment. Thus, the labor force is a pool of those who are economically active and thus directly available to carry out S/E functions.

Scientists and engineers continued to have a high participation rate in the labor force in 1981 with almost 94 percent (3.2 million) of the S/E population economically active.[13] This participation rate is higher than the 87 percent rate for the general population that has completed 4 or more years of college.[14] Differences in participation rates cannot be accounted for by differences in the sex composition of these groups. When further stratified by sex, S/E men have only slightly higher rates than S/E women (94 percent vs. 91 percent). By way of comparison, men and women who had completed 4 or more years of college had participation rates of 95 percent and 74 percent, respectively.[15]

Unemployment Rates

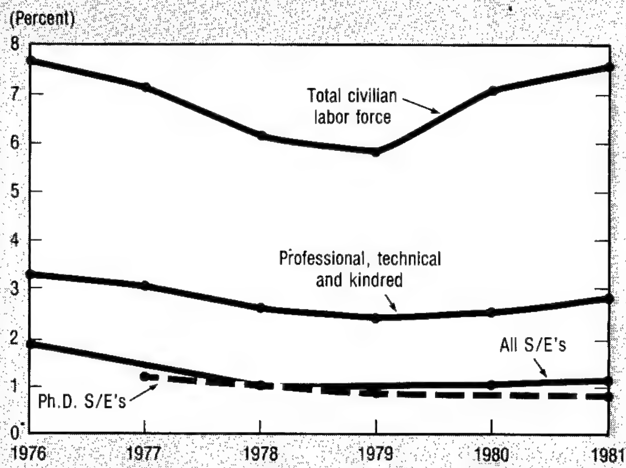
A standard measure of labor market conditions is the unemployment rate. The unemployment rate measures the proportion of those in the labor force who are not employed but seeking work. Relative to both the general labor force and all professional and related workers, S/E's have shown an improved and relatively strong labor market position. (See figure 3-13.) In 1976, the unemployment rate for S/E's was about 60 percent of that for all professional and technical workers; by 1981, that rate had fallen to about 39 percent. (See appendix table 3-15.)

[13]The labor force participation rate (LFPR) is the ratio of those employed (E) and those unemployed but seeking employment (U) to the population (P):

$$LFPR = \frac{E+U}{P}$$

[14]See ref. 6.
[15]See ref. 7.

Figure 3-13
Unemployment rates



See appendix table 3-15. Science Indicators—1982

Almost all scientists and engineers who want jobs are employed. Unemployment rates for scientists and engineers remained at about only 1 percent between 1978 and 1981. This stability follows the decline that occurred between 1976 and 1978, when the unemployment rate for S/E's fell from almost 2 percent in 1976.

There was some variation by field in the 1981 S/E unemployment rates. (See figure 3-14.) In 1981, the highest unemployment rate among scientists and engineers was posted by environmental scientists, but their rate of 2.5 percent was considerably below the 7.6 percent unemployment rate for the entire U.S. labor force and slightly below the 2.8 percent rate for all professional and related workers.

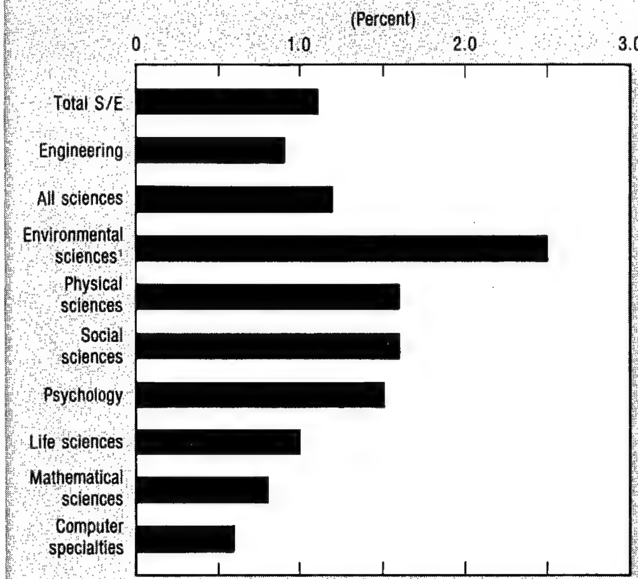
Preliminary data for 1982 suggest that unemployment rates for engineers[16] have increased slightly over 1981 rates (about 0.2 percentage points), but are still well below those for the entire labor force and for those in professional and related fields.

S/E Utilization Rates

Although unemployment rates are a standard labor market indicator, they do not indicate how successful those with S/E training are in finding jobs in science or engineering. While a low unemployment rate indicates that S/E's are not having difficulty finding jobs, it says nothing about their success in finding jobs in their area of expertise.

The S/E utilization rate has been developed to show the degree to which S/E's in the labor force hold science or engineering jobs.[17] In 1981, the S/E utilization rate was

Figure 3-14
Unemployment rates of scientists and engineers by field: 1981



[1]Includes earth sciences, oceanography, and atmospheric sciences.
See appendix table 3-16. Science Indicators—1982

about 88 percent, basically unchanged from the mid-1970's. The S/E utilization rate varies only slightly between engineers and scientists and among science fields. (See figure 3-15.) Although the S/E utilization rate is a good indicator of market conditions, some caution must be exercised in interpretation. Some who leave S/E jobs move to managerial positions that do not involve S/E activities. Others work outside of S/E activities for a variety of reasons not necessarily related to labor market conditions (e.g., strong location preference). Relatively few (about 10 percent) take non-S/E jobs because they cannot find S/E jobs.[18] Thus, small declines in the S/E utilization rates do not necessarily imply weak or declining markets.

S/E's holding doctorates showed a slightly higher S/E utilization rate than all S/E's combined. In 1981, the rate for all doctoral S/E's was 91 percent and, by field, ranged from 99 percent for computer specialists to 82 percent for social scientists. (See figure 3-16.) Variations among scientists with Ph.D.'s, however, were less than among all scientists.

Several inferences can be drawn from these indicators. The demand for computer specialists, engineers, and mathematical and life scientists is stronger than the demand for social or physical scientists. Furthermore, among science fields, the demand for those with doctoral degrees is stronger than the demand for those with other degrees.

Relative Salaries

Salary trends are another way of ascertaining labor market balance. If S/E's are in short supply, their salaries will

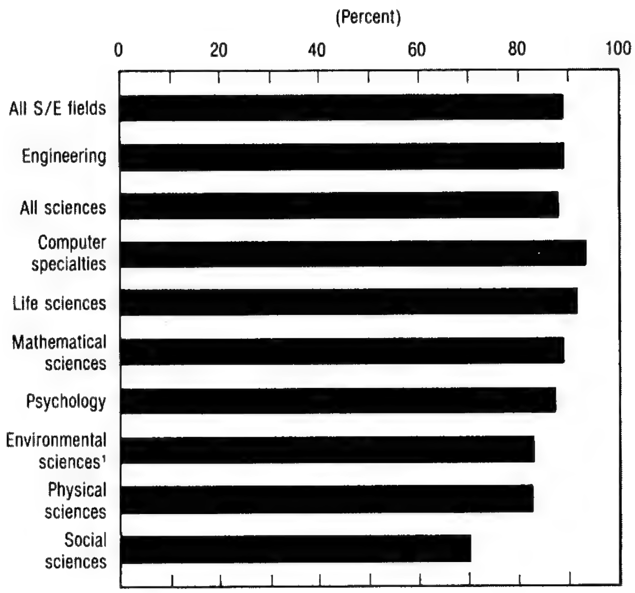
[16]See ref. 8.

[17]The S/E utilization rate (ES/E) measures the ratio of those holding jobs in science or engineering (S/E) to the total science and engineering labor force (LF), which includes those scientists and engineers employed in any job and those seeking employment:

$$ES/E = \frac{S/E}{LF}$$

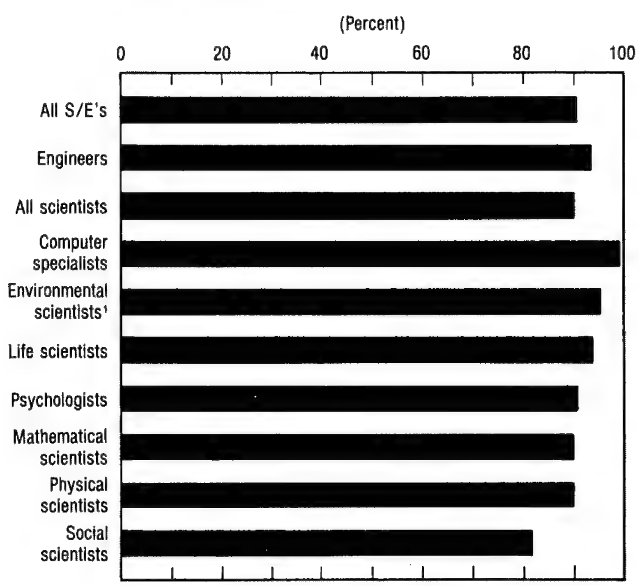
[18]See ref. 10.

Figure 3-15
S/E utilization rates by field: 1981



[1]Includes earth sciences, oceanography and atmospheric sciences.
See appendix table 3-17. Science Indicators—1982

Figure 3-16
S/E utilization rates for doctoral S/E's by field: 1981



[1]Includes earth scientists, oceanographers and atmospheric scientists.
See appendix table 3-17. Science Indicators—1982

ultimately be expected to increase relative to some general salary measure as employers increase their salary offers to attract the available supply. If salaries of S/E's increase at rates the same as or lower than for general salary levels, the inference is that the available supply is equal to or greater than the current demand for all personnel.

Starting salaries for new hires or inexperienced scientists and engineers can reflect the market situation for these occupations.[19] For scientists and engineers, starting-salaries are more sensitive to supply and demand conditions than salaries of experienced persons. The number of job offers made should also be considered. For example, while starting salaries were up in the humanities, the number of offers were down, indicating that the demand for those with degrees in the humanities was not strong. (See appendix tables 3-18 and 3-19.)

Starting salary offers for science and engineering graduates are generally higher than those for graduates in other fields. (See figure 3-17.) Engineering graduates traditionally receive higher starting salaries than do science graduates. Among science graduates, those with degrees in the computer, mathematical, and physical sciences have higher starting salaries than those in the life and social sciences.

According to the College Placement Council, engineering offers accounted for 57 percent of all offers to bachelor's candidates in 1982, down sharply from 1981 (65 percent of total offers) but about the same as 1977 (55 percent of total offers).[20] This decline from 1981 to 1982 can be attributed to a combination of factors: a) the decline of almost one-fifth in total offers to bachelor's candidates, and b) a substantial decrease in offers to chemical and mechanical engineering degree candidates (down almost one-half and one-third, respectively).

The recruiting volume (number of offers) accounted for by scientific disciplines was 13 percent of the total in 1982, up slightly from 1977 and 1981. Computer science degree candidates continued to dominate this category, comprising about one-half of the offers reported among science fields.

Annual salaries for recent S/E graduates increased at an annual rate of about 8 percent between 1976 and 1980. This rate is about the same annual increase noted between 1975 and 1980 for all male professional workers.[21] The information on starting salaries and numbers of offers indicates that the market demand for S/E's may be decreasing.

High Technology Recruitment

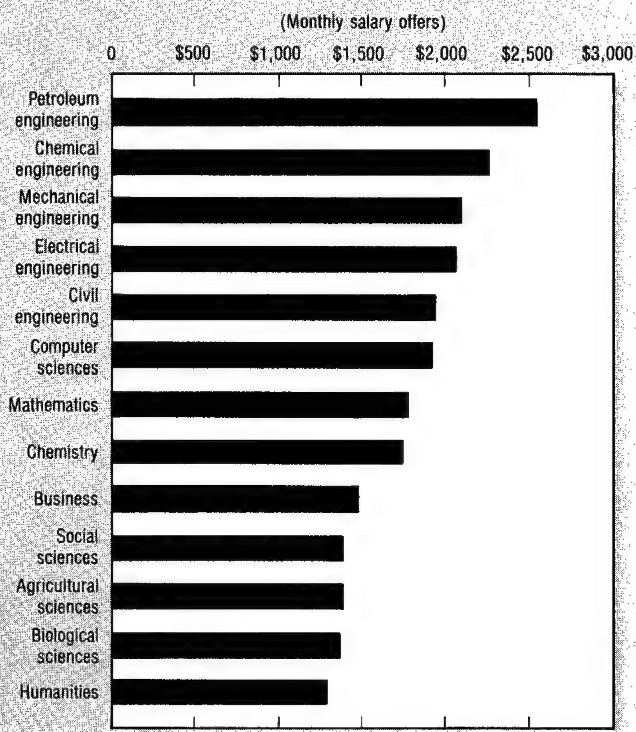
The High Technology Recruitment Index (HTRI) is also an indicator of market conditions for S/E's. The HTRI measures the amount of advertising space dedicated to recruiting scientists and engineers. In 1970, the index measured 60 (1961=100). In 1977, the index began a steady increase. (See figure 3-18.) However, demand (as measured by the HTRI) may have peaked. In 1982, it dropped to 104 from a 10 year high of 144 in 1979.[22]

Employment Status of Recent S/E Graduates

The employment status of recent S/E graduates is another indicator of labor market conditions. The market conditions for recent graduates provide a sensitive barometer of overall market conditions in various S/E fields

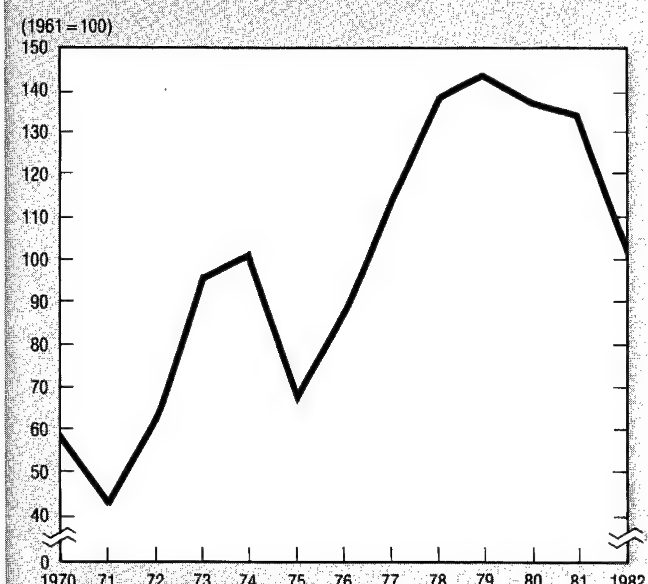
[19]See, for example, ref. 11 and ref. 9, pp. 10-16.
[20]See ref. 12, p. 3.
[21]See ref. 13 and National Science Foundation, unpublished data.
[22]See ref. 14.

Figure 3-17
Average monthly salary offers to bachelor's degree candidates in selected fields: 1981/82



See appendix table 3-18. Science Indicators—1982

Figure 3-18
Deutsch, Shea, and Evans High Technology Recruitment Index: 1970-82



See appendix table 3-21. Science Indicators—1982

since any change in employer demand is normally reflected first in employer hiring decisions. In addition, labor market conditions can cause students to alter decisions concerning college majors and possible careers.

The adequacy of recent S/E degree production in terms of employment demand can be indexed by the ratio of employment (classified by field of employment) to the labor force (classified by field of degree). Figure 3-19 depicts the ratio of S/E bachelor's, master's, and doctorate recipients employed in a field relative to the number of graduates in that field who entered the labor force. For example, are the number of graduates employed as chemists about the same as, more than, or less than the number of graduates in the labor force with degrees in chemistry? A ratio of 1.0 is consistent with relative supply and demand balance; ratios of less than 1.0 or more than 1.0 suggest a relative excess supply or relative excess demand, respectively.

Based on this index, the data suggest a relative supply and demand balance in engineering and chemistry and an excess supply in most other science fields, except for computer specialties which continue to reflect excess demand. (The index for engineering should be interpreted with some caution, however, since the nature of engineering jobs may make it difficult for those trained in other fields to work as engineers.) The data also suggest that the relative imbalances are somewhat smaller at the master's degree and doctorate levels, although the strong demand for computer specialists is evident among all degree recipients.

The indicators presented above reveal a mixed picture with respect to labor market conditions for scientists and engineers. All indicators point toward a shortage of computer specialists. For engineers, the indicators are mixed. While the indicators reveal a shortage in 1981, they also indicate that by mid- to late-1982, the situation appeared to be shifting from shortage to, at least, balance for engineers in general. There is some evidence that supply and demand conditions for chemists and possibly for life scientists may be in rough balance. For other science fields, supply is more than adequate. The indicators also show that surpluses are smaller at the master's and doctorate levels than at the bachelor's degree level.

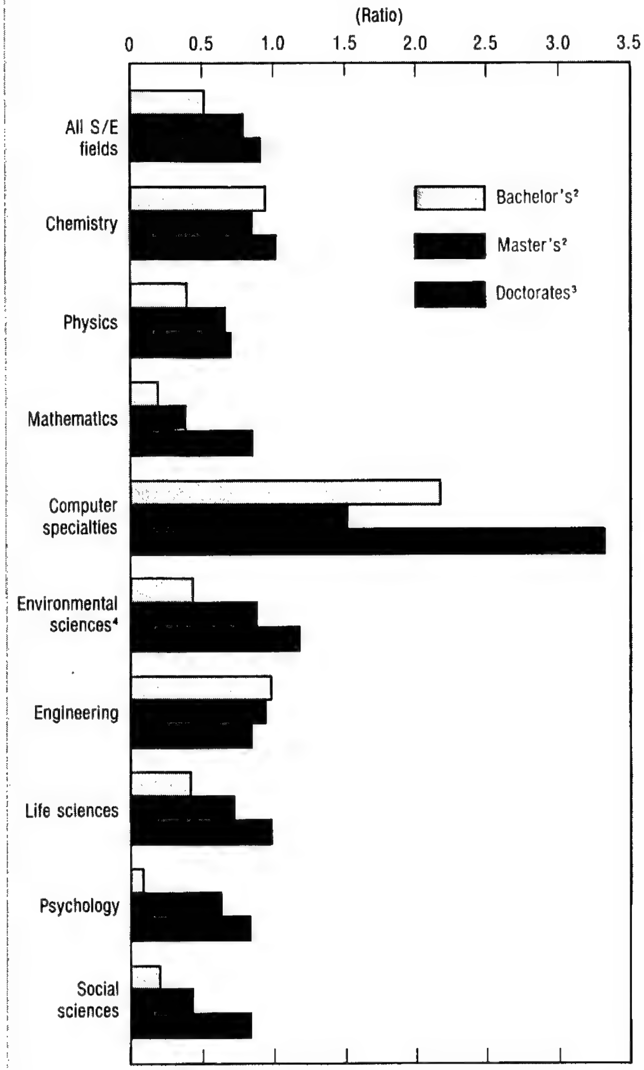
SCIENCE AND ENGINEERING PIPELINE

Both the quality and size of the potential pool of new scientists and engineers are causing concern from the perspective of science and technology policymakers, reflecting two separate but related developments. The first development focuses on the declining state of precollege mathematics and science education as demonstrated by the deteriorating performance of all precollege students on mathematics and science achievement tests and on declining scores on tests used in college admissions decisions, such as the Scholastic Aptitude Test (SAT). The second development relates to demographic factors, specifically the approximately 15 percent drop in the number of 18- to 24-year-olds anticipated during the 1980's. Furthermore, there is a concern that science and engineering may not be attracting as many highly able students as are other professions.

In order to illuminate these concerns, this section examines the science and engineering pipeline: from precollege mathematics and science education, to those earning

Figure 3-19

Ratio of recent science and engineering degree recipients[1] employed in field relative to graduates in field who entered the labor force



[1]Excludes full-time graduate students and those holding postdoctoral appointments.
[2]1978 and 1979 graduates in 1980.
[3]1977 graduates in 1979.
[4]Includes earth sciences, oceanography, and atmospheric sciences.
See appendix table 3-34. Science Indicators—1982

degrees in science and engineering, to the transition of S/E graduates from school to work.

Indicators useful in understanding and assessing precollege mathematics and science preparation include curriculum placement, specific coursework, and scores on tests measuring mathematics and science abilities and skills. These indicators are examined along with the relationship between students' decisions to study engineering or science and scores on the SAT. The section next examines degree production in science and engineering fields. In addition to statistics on earned degrees, data are presented relating the number earning degrees to various population or demographic factors. The quality of potential S/E graduate students is examined by reviewing Graduate Record Examination scores and other indicators of quality. A review of the transition of S/E graduates from school to work concludes the overview of the S/E pipeline. Indicators used to assess this transition are those associated with labor market activity and conditions such as labor force participation rates, and ability of graduates to find jobs in their own or related fields.

Precollege Mathematics and Science Coursework

Decisions not to take science and mathematics coursework in high school serve to diminish the supply of potential new entrants to S/E fields, since a strong background in these fields is usually required for access to postsecondary opportunities in science, engineering, and other quantitative fields. A student's curriculum is particularly important; it largely determines the type of coursework taken and is associated with future educational and career choices. Of high school seniors in 1980, 39 percent were in academic programs, 37 percent were in general programs, and 24 percent were in vocational programs.[23] Since 1972, the proportion of students in academic programs (a major source of future S/E students) declined by about 4 percentage points while the proportion in general programs increased by a like amount.

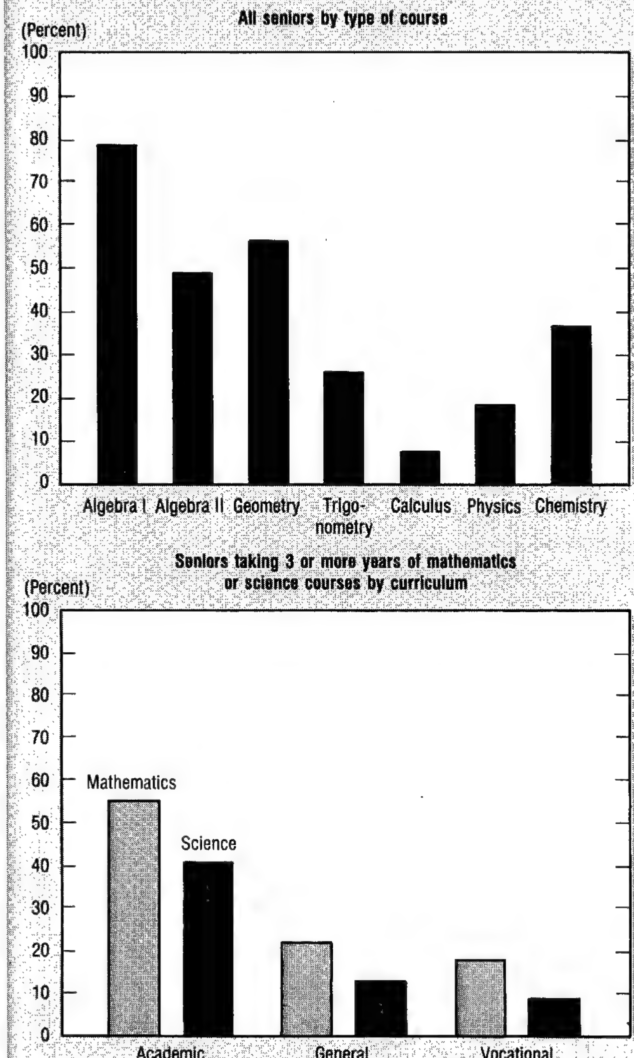
Because the population of high school graduates increased by almost 3 percent since 1972, the 4-point decline in the proportion of high school students in academic programs did not result in a very large decrease in the potential pool of new scientists and engineers. This decline may become a problem in the mid- to late-1980's, however, when the number of high school age persons in the population begins to decline.

Students in academic programs generally take more coursework in mathematics and science than do students in general or vocational programs. (See figure 3-20.) For example, over one-half of the seniors in academic programs in 1980 had taken 3 or more years of mathematics coursework, compared with only 18 percent of those in vocational programs.[24]

"College-bound seniors"—those students who take the SAT and respond to the Student Description Questionnaire (SDQ) administered by the Admissions Testing Program—numbered about 1 million in 1982 (one-third of the 1982 high school graduates) but represented about two-thirds of all graduates who go directly to college. In 1982, about 87 percent of college-bound seniors had taken 3 or more years of mathematics, compared to 55 percent of all 1980 high school seniors in academic programs. Of these college-bound seniors, 26 percent had studied mathematics at the high school level for 3 years, 50 percent for 4 years, and 11 percent for 5 years. (See figure 3-21.)[25]

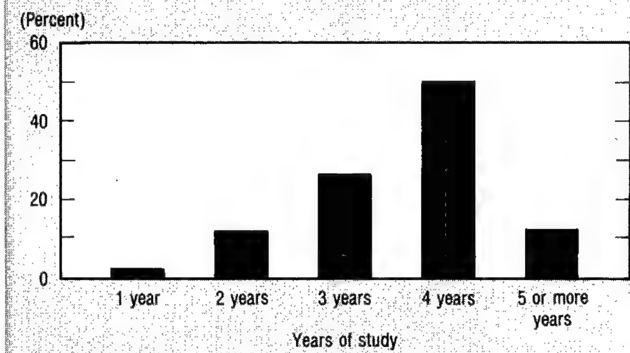
[23]See ref. 15, p. 3.
[24]See ref. 15, p. 5.
[25]Based on data from the Admissions Testing Program of the College Entrance Examination Board. See ref. 16, p. 14.

Figure 3-20
Percentage of high school seniors taking mathematics and science courses: 1980



NOTE: There were approximately 3 million high school seniors in 1980.
See appendix tables 3-22 and 3-24. Science Indicators—1982

Figure 3-21
Percentage of college-bound seniors taking mathematics by number of years of study: 1982



See appendix table 3-23. Science Indicators—1982

Mathematics and Science Achievement of Precollege Students

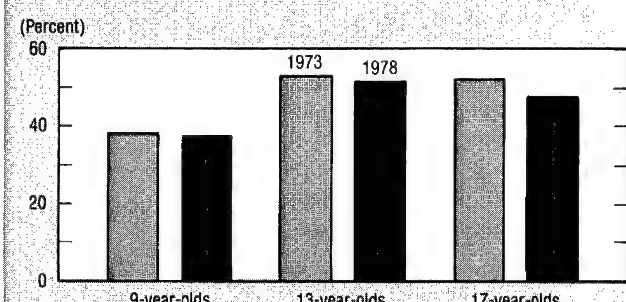
The National Assessment of Educational Progress (NAEP) is designed to assess the achievements of precollege students in a number of areas, including mathematics and science.[26]

Two NAEP assessments provide data on changes in mathematics achievement between the early and late 1970's.[27] These assessments evaluate performance for four different cognitive process levels: knowledge, skills, understanding, and application.

When all "change items" were considered together, the mathematics assessment showed that performance of 9-year-olds declined very slightly between 1973 and 1978. (See figure 3-22.) Average results for knowledge items showed no appreciable change over the 1973-1978 period. For skill items, results for 9-year-olds did not change; however, average skill levels of 13- and 17-year-olds declined, with 17-year-olds showing the largest drop. For items testing mathematical understanding, performance of 17-year-olds declined while the trend for 13-year-olds is unclear. All three age groups showed significant average declines on mathematical applications which involve the use of mathematical knowledge, skills, and understanding to solve problems.

Assessments of science achievement were also conducted by NAEP in 1969, 1973, and 1977. (See figure 3-23.) A downward trend in science achievement was observed in all three age groups from the first to the second assessment, but this decline appeared to be diminishing for 9-year-

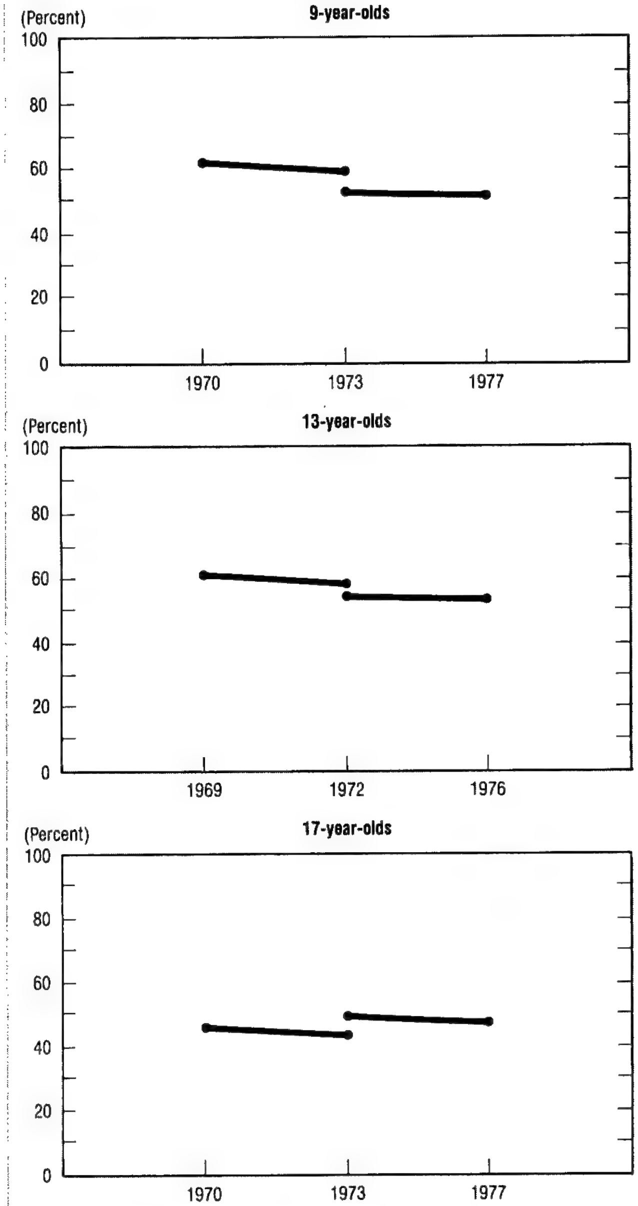
Figure 3-22
Average percentages of correct response on mathematics items by age and year



REFERENCE: National Assessment of Educational Progress, *Changes in Mathematical Achievement*, 1973-1978, Report No. 09-MA-01, (Denver, Colorado, August 1979), pp. 18-20.
Science Indicators—1982

[26]Other areas include art, career and occupational development, citizenship, literature, music, reading, social studies, and writing.
[27]See ref. 17, pp. 18-20.

Figure 3-23
Average correct response on science items by age and year



NOTE: At each age, one set of change items was administered in 1969-70 and 1972-73, while a second set of items was administered in 1972-73 and 1976-77.

REFERENCE: National Assessment of Educational Progress, *Three Assessments of Science, 1969-77: Technical Summary*, Report No. 08-S-21, (Denver, Colorado, April 1979), pp. 12-14.

Science Indicators—1982

olds and 13-year-olds in the third assessment. For these two age groups, it appears that a continued decline in physical science achievement accompanies some stability in biology achievement. The achievement of 17-year-olds declined throughout the three assessments.[28]

[28]See ref. 18, pp. 12-14.

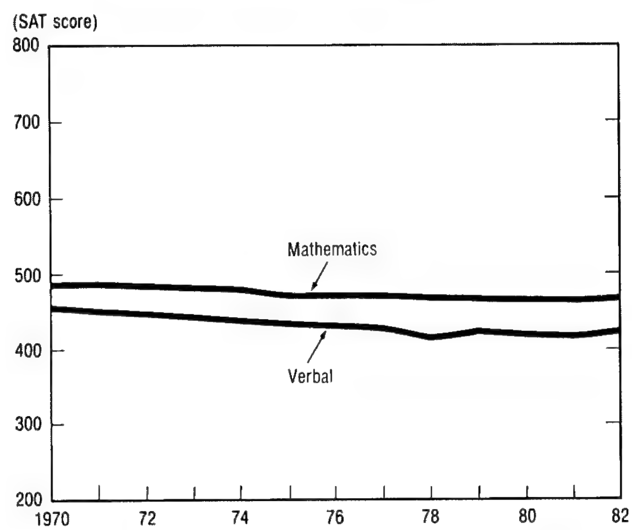
Aptitude Test Scores of Prospective S/E Students

The Scholastic Aptitude Test (SAT) is widely used in college admissions decisions. The test contains a verbal and a mathematics aptitude test and offers achievement tests in 15 academic subjects. Students who take achievement tests in mathematics and science generally have higher verbal and mathematics (quantitative) scores than other college-bound seniors, indicating that there is some self-selection occurring in the potential choice of college major. A relatively low score on the mathematics part of the test could inhibit a student's choice of major or acceptance for study in a science or engineering field.

Even though scores increased slightly between 1981 and 1982, between 1970 and 1982 average verbal SAT scores declined by 34 points (460 to 426), while average mathematics scores declined by 21 points (488 to 467). (See figure 3-24.)[29] These declining scores can be attributed to many factors, including greater proportions of average and marginal-achieving students taking the exam. However, an advisory panel for the Educational Testing Service (sponsors of the exam) concluded that only one-fourth of the decline since 1970 could be explained by this factor. Other contributing factors included changes in school curricula, i.e., reduction of required courses, and the impact of television in stressing listening and viewing skills rather than active participation.[30]

The steady decline in overall SAT scores is not reflected in the SAT scores of college-bound seniors intending to major in a science or engineering field.[31] These students

Figure 3-24
Scholastic Aptitude Test (SAT) score averages for college-bound seniors: 1970-82



See appendix table 3-25.

Science Indicators—1982

[29]Score range for the SAT is between 200 and 800.
[30]See ref. 19.
[31]See ref. 20.

generally had higher overall scores than all college-bound seniors. (See table 3-2.) The overall average verbal and mathematics scores of college-bound seniors were 426 and 467, respectively. Students planning to study engineering had average verbal scores of 446 and average mathematics scores of 534; for those planning to study the physical sciences, the average scores were 496 (verbal) and 558 (mathematics). When those planning to major in science and engineering are combined, the average scores are estimated to be 446 (verbal) and 503 (mathematics) for 1982.

The indicators presented above on high school mathematics and science coursework and on the results of various standardized tests document the declining state of precollege mathematics and science education. The proportion of students in high school academic programs has declined. Since students in these programs take more mathematics and science courses than other students, the decline in the proportion in academic programs is cause for concern. Moreover, the performance of high school students on standardized achievement tests has declined over the 1970's, and shows that children at all ages are deficient in their ability to apply mathematics skills to solve problems. Thus, it comes as no surprise that scores on both the verbal and mathematics portions of the SAT have also declined over the 1970's. The declining state of precollege mathematics and science education has negative implications for overall mathematics and science literacy—the ability of citizens to function in an increasingly technological environment. When combined with the anticipated drop in the number of high school students, the declining state of precollege education also has serious implications for the size of the pool of students from which scientists and engineers are drawn.

On a more positive note, the decline in SAT scores is not reflected in the scores of high school seniors planning to major in science or engineering. These students generally had higher SAT scores, especially in mathematics, than students planning to major in nonscience or engineering fields.

Table 3-2. Average (mean) SAT scores of college-bound seniors by intended undergraduate major: 1982

Intended undergraduate major	Verbal	Mathematics
All college-bound seniors	426	467
Business	401	446
Education	394	419
All science and engineering	446	503
Physical science	496	558
Mathematics	455	569
Computer science	417	489
Engineering	449	537
Biology	472	504
Agricultural sciences	402	436
Psychology	436	446
Social science	461	475

SOURCE: Admissions Testing Program of the College Board, *National College-Bound Seniors, 1982* (Princeton, N.J.: Educational Testing Service, 1982), p. 18.

Science Indicators—1982

S/E Degree Production

The number of S/E bachelor's degrees awarded annually has exhibited two distinct phases since 1955: a) a continuous rise from 1955 to 1974; and b) a decline of about 3 percent between 1974 and 1981. (See figure 3-25.) The first phase reflects a variety of factors that combined to sustain this remarkably long period of growth. "Sputnik," launched in October 1957, influenced the passage of the National Education Defense Act of 1958, authorizing direct, low interest student loans, graduate fellowships, and several forms of assistance to institutions. The Higher Education Act of 1965 initiated major student assistance programs, including work study and educational opportunity grants and insured loans that became effective in FY 1967. Furthermore, the first wave of the postwar baby boom generation reached college-age in the mid-1960's. Finally, the possibility of being drafted provided an incentive to enroll in college during part of the 1955-74 period. However, such incentives ended with the elimination of student deferments in 1971 and the institution of an all-volunteer army in 1973.[32]

During the second phase, the availability of student aid increased, total enrollments in higher education continued to grow, and demographic declines had not yet reduced the size of the traditional college-age population. On the other hand, the proportion of part-time and unclassified[33] students increased, the S/E share of total bachelor's degrees remained almost constant between 1974 and 1981, and the number of S/E bachelor's degrees per thousand 22-year-olds declined.

These trends varied considerably by field. (See figure 3-25.) The most notable trend was in engineering, which showed an increase of 64 percent from 1976 to 1981 when it reached an historic high of about 64,000. The relatively level trend in physical sciences masks a 35 percent decrease in physics since 1970 and an increase of 100 percent in geological sciences. Degrees in mathematical sciences have fallen by 9 percent since 1970, but this conceals two divergent trends. Although degrees in mathematics have fallen 59 percent (from 27,600 in 1970 to 11,200 in 1981), degrees in computer science have risen from 1,500 to over 15,000; some of this increase may be due to a reclassification of earned degrees.

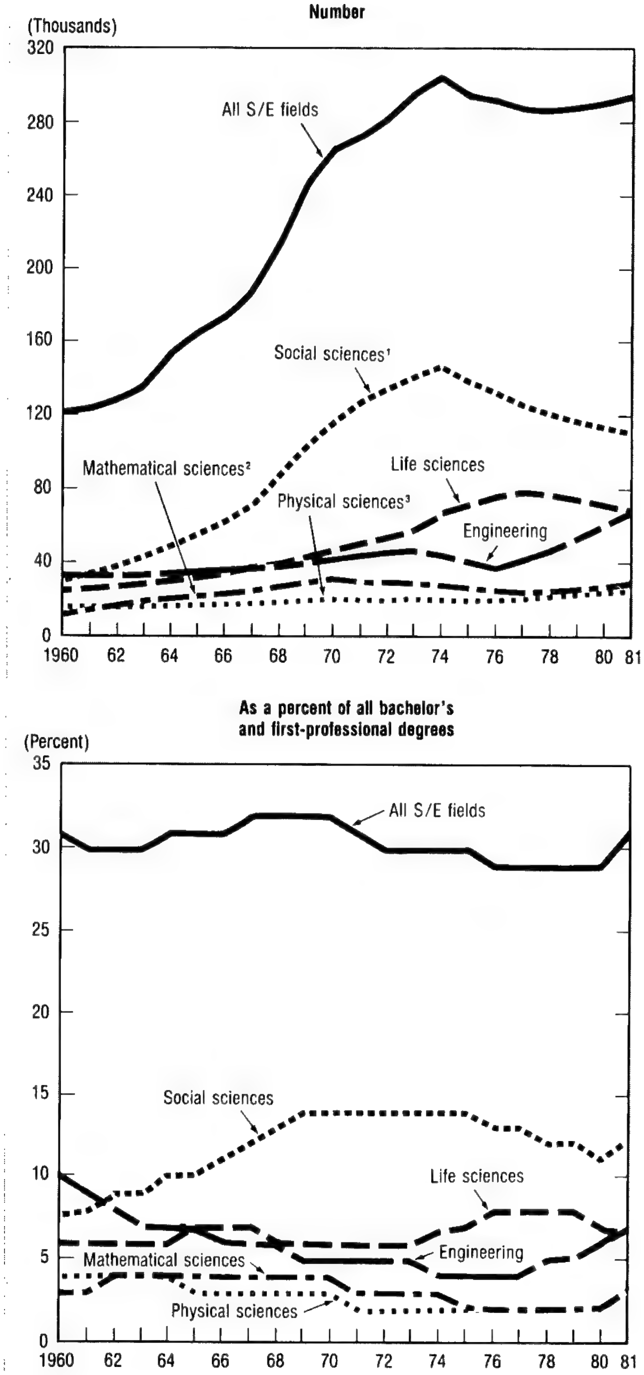
Although the size of the traditional college-age population is considered to be one of the basic factors in determining degree production potential, only about 40 percent of the 1955-1981 increase may be attributable to demographic changes. In 1955, the lowest year in the production of S/E bachelor's and first-professional degrees since World War II, there were about 2.1 million persons 22 years of age (the normal age for baccalaureate recipients); 39 S/E degrees were awarded per thousand 22-year-olds. If this 1955 rate of degree production had remained constant, the number of degrees produced in 1981 would have been about 163,000 rather than the 295,000 which were produced.

The remainder of the 1955-1981 increase, about 60 percent, may be attributed to the higher rate of participation

[32]See ref. 21.

[33]Unclassified students are those who are not candidates for a degree or other formal award, although they are taking courses for credit in regular classes with other students.

Figure 3-25
Science and engineering bachelor's and first-professional degrees awarded by field



[1]Includes psychology.
[2]Includes computer sciences.
[3]Includes environmental sciences.
See appendix table 3-27.

Science Indicators—1982

in college for those in the 18- to 22-year-old age group. Factors influencing the high rate include, in addition to interest in S/E careers: changes in the value of education as perceived by young people, their parents, and employers; the availability of desired educational opportunities; and the economic capability of would-be students, including the availability of various types of student aid.

Population projections do not indicate any major change in the number of 22-year-olds by the mid-1980's. Therefore, demographic factors should have little influence on the number of bachelor's degrees in the near future, and changes over the next few years will be primarily the result of changes in nondemographic factors. However, from the mid-1980's through 1990, the population of 22-year-olds is projected to decrease to about 17 percent less than the estimated 1980 population, suggesting that degree production could decline if demographic factors predominate.

In 1981, about 295,000 bachelor's degrees were granted in science and engineering, as well as about 55,000 master's degrees and 18,000 doctorates. (See figures 3-25, 3-26, and 3-27.) The number of S/E master's degrees increased during the 1970's, peaking at 56,700 in 1977 and declining to 54,800 by 1981. The pattern in S/E doctorates was similar to that of S/E bachelor's degrees; after climbing steadily, but at a decreasing rate, the number peaked in 1973 and began to decline. By 1981, the number of S/E doctorates granted was about 7 percent below the 1973 level.

As discussed earlier, the number of 22-year-olds affects the number of bachelor's degrees produced. Analogously, the number of bachelor's degree recipients defines the pool from which recipients of graduate degrees are drawn when the appropriate number of years are added.[34] Although the time period required to complete a degree is not the same for all advanced degree recipients, on the average, S/E master's degrees may be appropriately related to bachelor's degrees received 2 years earlier and doctorate degrees may be related to bachelor's degrees received 7 years earlier.[35] S/E master's degrees as a percentage of bachelor's degrees received 2 years earlier (the continuation rate) increased from almost 19 percent in 1957 to 26 percent in 1968, then declined to 19 percent in 1974 and remained near that level through 1981.[36] If the 26 percent rate of the late 1960's had been achieved in 1981, the number of S/E master's degrees would have increased by more than 31,000, from 45,000 in 1968 to 76,000 in 1981. The actual increase was only about 9,400.

The same general pattern occurred at the doctorate level. The highest continuation rate (13 percent) was not reached until 1970, and the subsequent decline (to 6 percent) in 1981 was relatively more severe than the decline in the rate for master's degrees. If the rate had remained at the high of 13 percent, annual production of S/E doctoral degrees would have increased by about 22,000, from 17,600 in 1970 to 39,200 in 1981; however, actual degree production fell slightly.

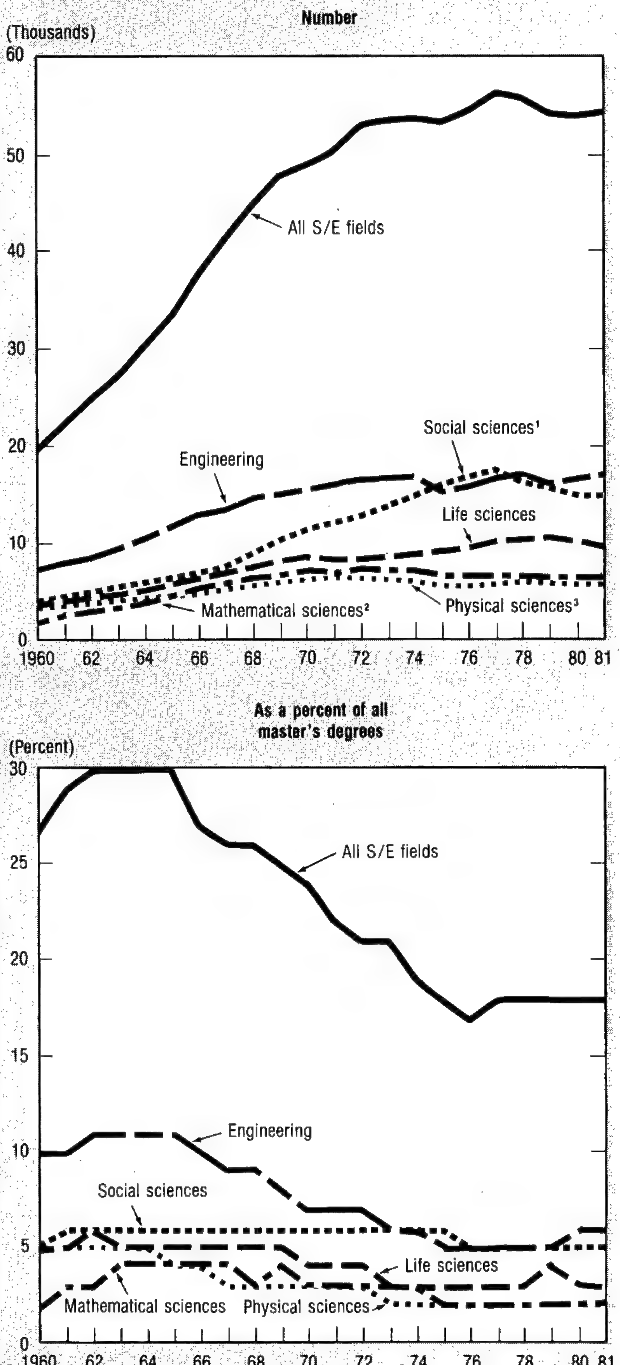
The trends in earned degrees and continuation rates outlined above also have implications for the S/E share of

[34]This pool is limited to S/E degrees although it is recognized that some S/E baccalaureates may receive advanced degrees in nonscience fields and vice versa.

[35]For a discussion of the baccalaureate-to-doctorate time lapse, see ref. 22, pp. 54-55.

[36]Bachelor's degrees in 1955 are used as the starting point to avoid the years with large numbers of World War II veterans.

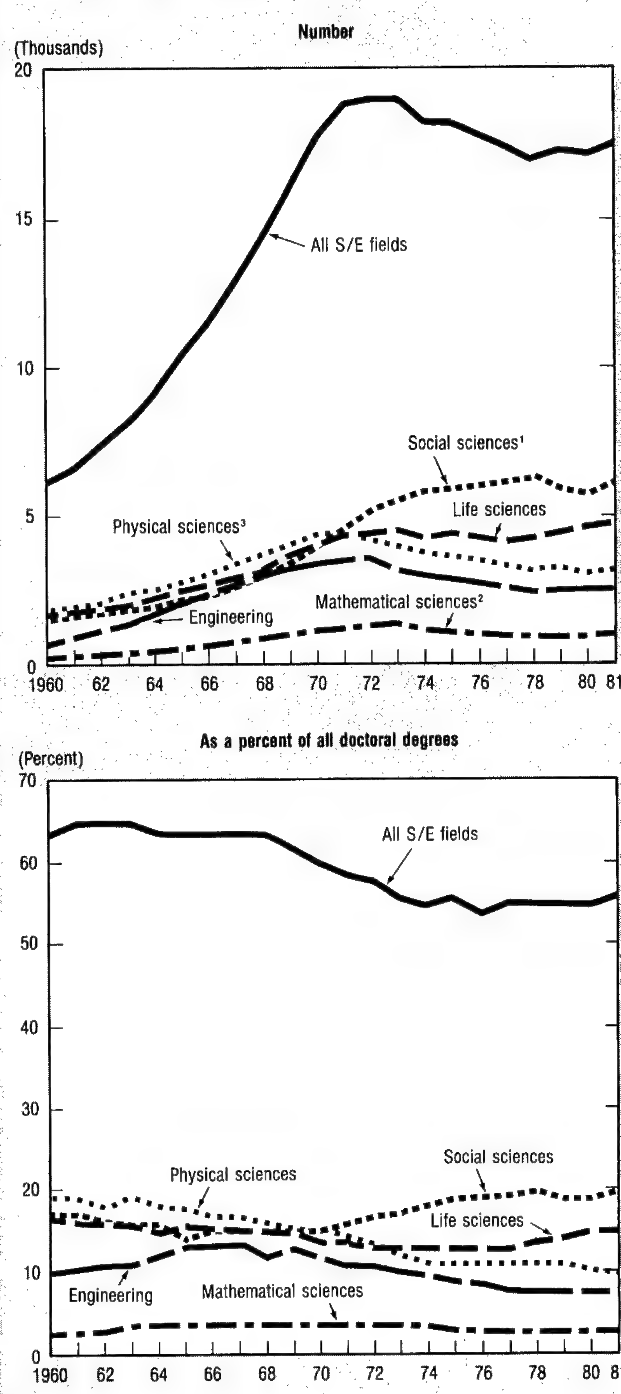
Figure 3-26
Science and engineering master's degrees awarded by field



[1]Includes psychology.
[2]Includes computer sciences.
[3]Includes environmental sciences.
See appendix table 3-28.

Science Indicators—1982

Figure 3-27
Science and engineering doctorates awarded by field



[1]Includes psychology.
[2]Includes computer sciences.
[3]Includes environmental sciences.
See appendix table 3-29.

Science Indicators—1982

total degrees. At the bachelor's level, this share was relatively stable at slightly above 30 percent until 1970, when it began to decline gradually. (See figure 3-25.) By 1981, S/E degrees represented about 31 percent of the total. For master's degrees, the share declined steadily from 30 percent in 1965 to 17 percent in 1976. (See figure 3-26.) This trend was primarily the result of the dramatic decline in the share of engineering degrees, which dropped by about 50 percent. Between 1976 and 1981, S/E master's degrees as a percent of all master's degrees remained relatively stable at roughly 18 percent. (See appendix table 3-28.) For S/E doctorates, the trend roughly paralleled the trend for master's degrees; the S/E share declined from 64 percent in 1975 to 54 percent in 1976 and increased slightly in 1981. (See figure 3-27.)

Quality of Prospective Graduate Students

Graduate Record Examination (GRE) scores are one widely used factor in appraising the future performance of applicants for graduate study. Two types of tests are available—the Aptitude Test and the Advanced Test.[37] The Aptitude Test is basically a measure of developed abilities and attempts to measure skills acquired over a long period of time. It is not related to any specific field of study. The Advanced Tests are measures of achievement in particular fields of study, and each Advanced Test assumes either an undergraduate major or extensive background in the specific subject.

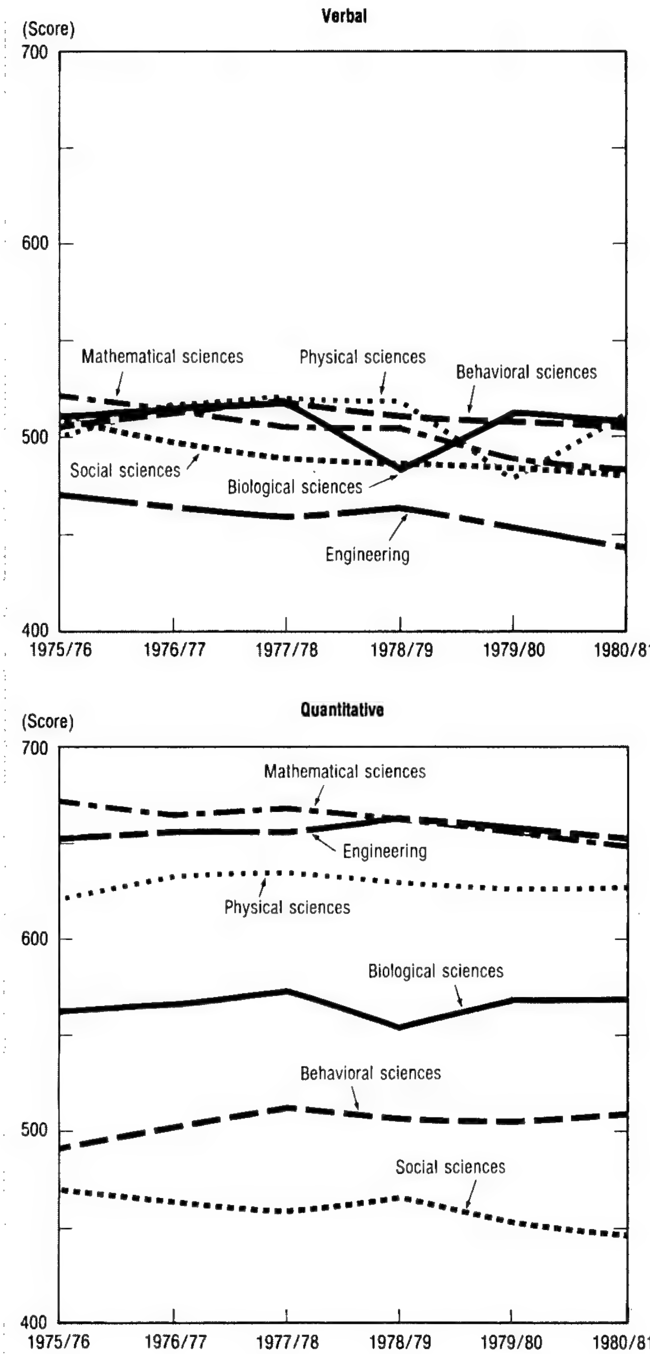
Based on the verbal and quantitative components of the Aptitude Test, the quality (scores) of prospective S/E graduate students remains high in absolute terms and relative to overall average scores and scores of prospective students in nonscience fields.

Mean aptitude test scores are available from 1976 to 1981 for several S/E fields. (See figure 3-28.) In verbal ability, scores for science and nonscience students did not differ significantly, but engineering candidates' scores averaged noticeably lower than scores of science candidates. The lower verbal scores for engineering candidates may be influenced by the relatively large number of foreign students entering graduate engineering programs.[38] In quantitative ability, candidates for admission to S/E fields scored significantly higher than candidates in nonscience fields, but there were large differences separating candidates in engineering, mathematics, and physics from those in the life and social sciences.

Not only has the quality of prospective graduate students remained fairly constant, but the proportion of doctorates granted by top-rated departments for selected fields has been relatively stable from 1967 to 1978. Although the number of S/E doctorates granted has declined since the early 1970's, excluding social science degrees, the downward trend in the number of doctorates awarded by those with a "distinguished" Roose-Anderson rating has proceeded at a slower rate than the trend in lesser rated departments.[39]

[37]For further information, see ref. 23.
[38]See chapter on Academic Science and Engineering.
[39]See ref. 24.

Figure 3-28
Mean scores on the verbal and quantitative portions of the Graduate Record Examination by prospective graduate major



See appendix table 3-26.

Science Indicators—1982

Other Measures of Quality

National Science Foundation graduate fellowships are competitively awarded and designed to support the "best" graduate students in science and engineering fields. Given the declines in the number of S/E doctorates awarded over

the 1970's, the question arises as to whether the quality of applicants for NSF fellowships has declined. Both GRE Aptitude and Advanced Test scores of applicants for NSF Graduate Fellowships have remained stable over the past decade.[40] In addition, the test scores of NSF fellowship applicants are above those for all prospective graduate students. For example, NSF fellowship applicants in chemistry averaged verbal scores of about 600 and quantitative scores of about 700 in 1980. For all chemistry applicants, the average scores were 516 (verbal) and 637 (quantitative).

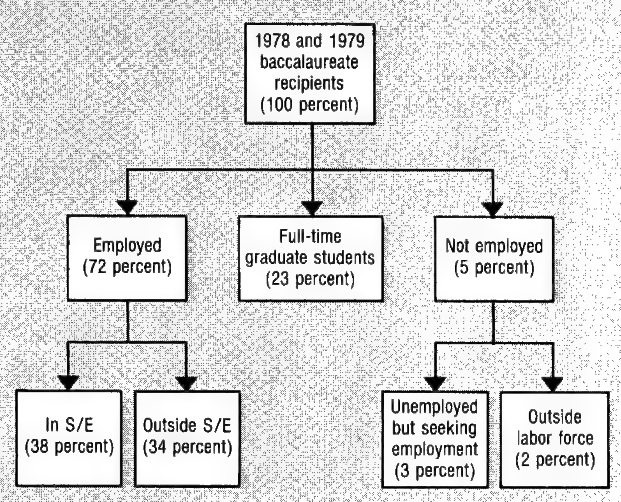
Another measure of the quality of prospective graduate students is the test scores of applicants to "leading graduate schools." A study of those schools selected by the largest number of NSF Graduate Fellowship awardees over the 1978-1980 period shows that the quality of all students sending score reports to leading schools of engineering and science, as reflected in GRE Advanced Test scores, has remained at a high level over the 1975-1980 period, although the actual number of such students has declined appreciably in most fields.[41]

Transition from School to Work

The transition of recent S/E graduates at all degree levels from school to the work force completes the S/E pipeline which started at the precollege level. The transitions of recent bachelor's recipients are shown in figure 3-29. Only a fraction of those earning S/E degrees in 1978 and 1979 were employed in science or engineering jobs after graduation. This low rate can be attributed to several factors. First, a substantial number of graduates,[42] especially at the bachelor's level, postpone entry into the labor force by pursuing full-time graduate study. Second, a small fraction are not employed, either because they choose to remain outside the labor force or because they are unable to find employment. Finally, not all individuals who find employment, especially at the bachelor's level, are employed in S/E jobs, in part because more than a bachelor's degree may be required for entry level jobs in certain scientific fields.

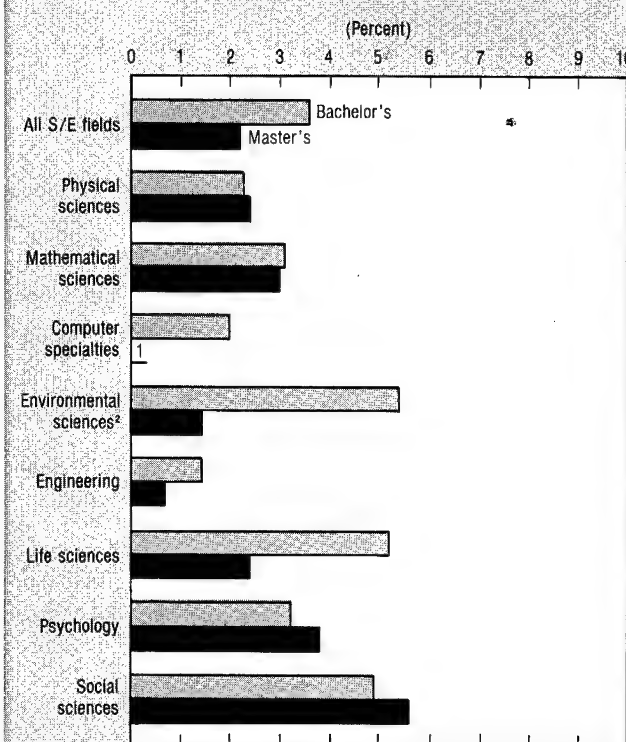
After graduation, a large proportion of S/E degree recipients enter the labor force. Of those earning their degrees in 1978 and 1979, 85 percent of those with bachelor's degrees and 75 percent of those with master's degrees were in the labor force in 1980, including those who were also full-time graduate students and employed. About 90 percent of those not in the labor force—at both bachelor's and master's levels—were full-time students. At the doctoral level, labor force participation rates of well over 90 percent were reported by recent graduates. Excluding full-time graduate students, most recent S/E graduates in the labor force have jobs. At the bachelor's level, 3.6 percent were unemployed as were 2.2 percent at the master's level and 1.4 percent at the doctoral level. As expected, unemployment rates among recent S/E graduates vary by both field and level of degree. (See figure 3-30.) The highest

Figure 3-29
Transition of 1978 and 1979 baccalaureate recipients in S/E fields from school to work: 1980



Based on appendix table 3-30. Science Indicators—1982

Figure 3-30
Unemployment rates of recent S/E graduates by field and degree level



¹Too few cases to estimate.
²Includes earth sciences, oceanography and atmospheric sciences.
Based on appendix tables 3-30 and 3-31.
NOTE: These data are the 1980 unemployment rates for the 1978 and 1979 graduates. Science Indicators—1982

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[40]See ref. 25.

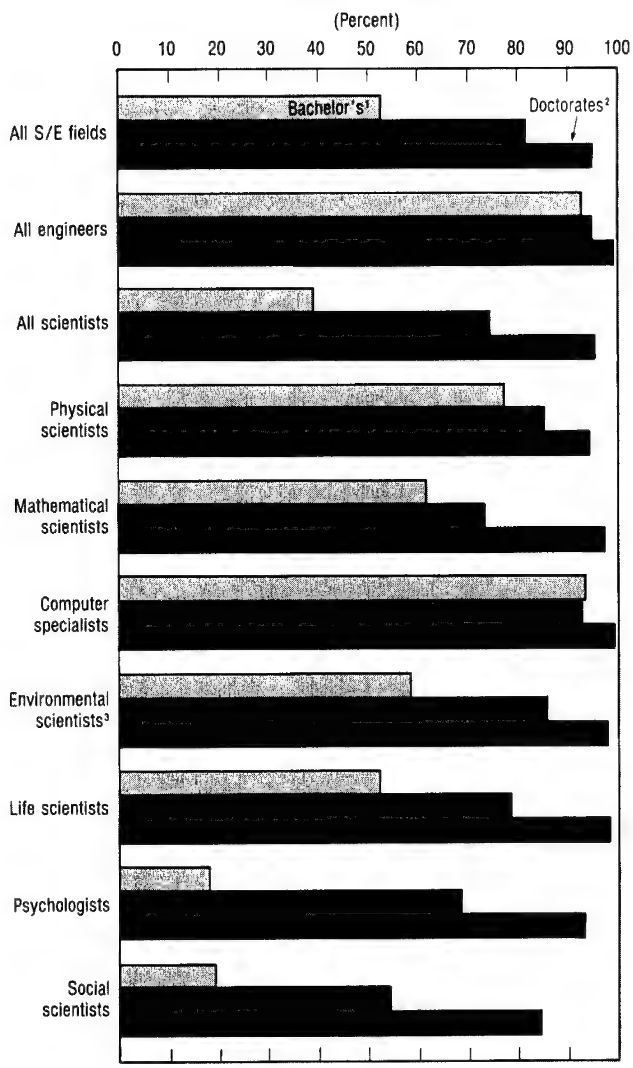
[41]*Ibid.*

[42]In 1980, 23 percent of the 1978 and 1979 S/E bachelor's degree recipients were full-time graduate students.

unemployment rates were found among those with only bachelor's degrees and among those with degrees in the social sciences at all levels.

The propensity of recent S/E graduates to hold jobs in science or engineering varies by both field and level of degree. (See figure 3-31.) About one-half of the recent (1978-1979) employed bachelor's degree graduates and over 80 percent of the employed master's degree graduates reported that they were in S/E jobs in 1980. Also about 95 percent of the employed 1979 doctorate recipients held S/E jobs in 1981. Among major fields, the proportion in S/E jobs was consistently higher for engineering and computer science graduates and lower for social science graduates, particularly at the bachelor's level.

Figure 3-31
S/E employment rates of recent S/E degree recipients by degree level and field



[1]1978-79 graduates in 1980.
[2]1979 graduates in 1981.
[3]Includes earth scientists, oceanographers and atmospheric scientists.
Based on appendix tables 3-30, 3-31, and 3-32. Science Indicators—1982

One of the factors contributing to the low overall proportion of recent S/E graduates holding S/E jobs is that, for some science fields, the entry level may be the master's degree rather than the bachelor's degree. Thus, relatively few recent graduates at the bachelor's level are employed in their field or in other science occupations. To some extent, employers may be screening by level of education because the supply greatly exceeds the demand. However, an increase in the educational level necessary to enter a field may also reflect informed opinion that graduate education is generally necessary to do professional work in a field.

A final measure of the transition of recent graduates from school to work is the proportion of those employed who find jobs in their own field. At the bachelor's level, almost 45 percent of those employed found jobs in their own field, as did about 75 percent of the master's graduates. In-field employment rates varied by field, with those for engineering and computer specialties generally higher than the rates for other fields. (See appendix table 3-33.)

The indicators outlined above show that almost all S/E graduates make a successful transition from school to work. Labor force participation rates are high and unemployment rates are relatively low. However, the indicators also show that only about one-half of those earning S/E degrees at the bachelor's level find jobs in science or engineering with the proportions for engineers and computer specialists higher than in other S/E fields. The propensity to find jobs in science or engineering increases with educational attainment.

OVERVIEW

Recently, employment in science and engineering has grown more rapidly than total U.S. employment and overall economic activity, implying shifts in de facto national priorities toward those related to science and technology. Underlying these shifts has been a very rapid increase in employment of computer specialists and a relatively slow growth in engineering employment. Recent growth in engineering employment, however, has been inhibited by a lack of qualified applicants for available jobs. With respect to sectoral employment patterns of scientists and engineers, there has been a slight shift toward industry and away from educational institutions and the Federal Government.

Employment of women and racial minorities in science and engineering since the mid-1970's has increased more rapidly than employment of men and white S/E's. Despite their more rapid growth, however, women and racial minorities (except Asians) continue to be underrepresented in science and engineering.

There are shortages of computer specialists and, to a lesser extent, of engineers. However, preliminary 1982 data suggest that, in general, supply and demand conditions for engineers may be changing to a state of balance, although there still may be shortages in some engineering fields. There are more than adequate supplies of environmental, physical, and social scientists and of psychologists. In other science fields, there is a rough balance between supply and demand.

The declining state of precollege mathematics and science education and the anticipated drop over the 1980's in

the college-age population are causing concern about both the quality and size of the potential pool of scientists and engineers. The science and engineering pipeline begins with the precollege mathematics and science preparation of students and ends when those earning degrees in science and engineering enter the world of work.

High school students enrolled in academic programs generally take more mathematics and science coursework than students in general or vocational programs. However, the proportion of students in academic programs (a major source of future science and engineering students) declined by about 4 percent between 1972 and 1980. This downward trend in the proportion of students in academic programs takes on added importance when combined with the expected decline in the number of high school students in the 1980's. Furthermore, the performance of high school students on tests designed to measure both mathematics and science achievement has declined over the 1970's as have scores on both the verbal and mathematics components of the SAT. The steady decline in SAT scores, however, is not reflected in the SAT scores of college-bound seniors planning to major in science or engineering. Moreover, average mathematics scores were generally higher for those planning to study engineering or the natural sciences than for those planning other areas of study.

Over the 1970's, the science and engineering share of total bachelor's degrees declined slightly, and the number earning degrees in science and engineering in 1981 was about 3 percent below the peak year of 1974. The number earning degrees in the physical sciences has remained stable, masking about a 35 percent decline in the number earning degrees in physics and an increase of more than 100 percent in the number earning degrees in the geological sciences. The number earning degrees in the mathematical sciences has fallen about 9 percent since 1970, but the drop conceals two divergent trends: a) a substantial drop in those earning mathematics degrees (59 percent between 1970 and 1981) and b) an almost eightfold increase in the number of students earning degrees in computer science. In contrast to the generally declining number earning degrees in the sciences, the number earning degrees in engineering increased by more than 40 percent between 1970 and 1981, reaching an historic high of about 64,000 in 1981.

Almost all graduates with bachelor's degrees in science and engineering find jobs, although only slightly more than half find work in their own or related fields. This proportion varies between engineers and scientists and among science fields, and the propensity of recent S/E graduates to find jobs in science or engineering also varies by level of education. The propensity increased from about 50 percent at the bachelor's level, to over 80 percent at the master's level, to about 95 percent at the doctoral level.

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Chapter 4
Industrial Science and Technology

Industrial Science and Technology

HIGHLIGHTS

- Employment of scientists and engineers (S/E's) in industry has risen steadily between 1976 and 1981, from about 1.3 million to almost 1.9 million, an increase of about 47 percent. This growth was paced by the very rapid increase of computer specialists (122 percent), while scientists grew at twice the rate for engineers (70 percent vs. 35 percent). Employment increases for scientists and engineers significantly outpaced increases in total industrial employment (47 percent versus 15 percent between 1976 and 1981). The more rapid increase for scientists and engineers results from the relative concentration of S/E's in high technology industries, where overall employment is increasing rapidly, and from changes in the occupational mix of industrial employment. (See pp. 87-88.)
- The largest growth in S/E industrial employment was among those primarily working in production-related jobs, such as quality control. The increase was over 60 percent between 1976 and 1981. Engineers were the major component of this growth. Increasing S/E employment in production and related activities reflects the added emphasis U.S. industry is placing on improving its productivity, quality control, and international competitiveness. (See p. 89.)
- Private industry continues to be the main performer of research and development (R&D) in the United States. In 1981, R&D funding in industry reached $52 billion, which constitutes 72 percent of all U.S. R&D expenditures—an all-time high even in constant dollars. While the rate of increase was 6.5 percent per year in constant dollars from 1979 to 1981, slower increases are forecast for the next few years. (See p. 92.)
- Since 1967, private industry itself has been the main source of funding for industrial R&D. Private funding increased by 7.3 percent per year in constant dollars from 1977 to 1981, reaching $35 billion in current dollars in 1981. This growth decelerated in the early 1980's because of economic uncertainty. The impact of the administration's R&D tax incentives is not yet apparent. (See pp. 92-93.)
- While constant-dollar Federal support for industrial R&D is below the level of the early 1960's, the Government still supports about a third of all industrial R&D. The administration is planning for major growth in real military spending from 1982 to 1987. This buildup will particularly affect R&D in the aircraft and missiles and electrical equipment industries. (See pp. 93-99.)
- The aircraft and missiles and electrical equipment industries are the leading R&D-performers, each spending about 20 percent of all industrial R&D funds. The former is also the only industry receiving more than half of its R&D funding from the Government. Within the electrical equipment industry, especially large R&D increases occurred from 1978 to 1980 in communication equipment (9.4 percent per year) and electrical components (16.5 percent per year). These increases are due in part to increased private funding in communication equipment and increased Federal funding in high speed integrated circuits. (See pp. 94-97.)
- The amount of R&D funding spent abroad by U.S.-based multinational companies more than doubled from 1974 to 1980, though it did not increase from 1980 to 1981. It now amounts to nearly 10 percent of private industry's R&D funds spent within the United States. This foreign activity is concentrated in the automobile, communication equipment, chemical, and nonelectrical equipment areas. Benefits to the United States occur because increases in the level of domestic R&D are promoted as a result, and because technology from the foreign affiliate is often transferred back to the United States. In 1979, an estimated 47 percent of overseas R&D resulted in such transfer. (See pp. 97-99.)
- The number of successful patent applications by American inventors declined at an average rate of 1.7 percent per year from a high point in 1969 to a low point in 1979. This indicates a decline in the production of technical inventions, particularly by corporations. However, from 1979 to 1982 successful applications are estimated to have increased by 1.5 percent per year. Still, the estimated 1982 level is 12 percent lower than the 1969 maximum. (See pp. 99-102.)
- Small companies produced 19 percent of all patents from U.S. corporations in 1980. This is well above their share of corporate R&D expenditure, which is less than 5 percent, and suggests that small companies are especially inventive. However, many of the inventive activities of small companies occur outside their formally designated R&D. (See pp. 104-105.)
- The financing of high technology small businesses helps to insure the continued production of technological innovations in U.S. industry. While the number of initial public offerings of stock in such companies dropped to zero in 1975, it rose to 170 in 1981, the highest level in at least 10 years. Similarly, venture capital investments in high technology companies increased from $72 million in 1975 to $425 million in 1980. Most of this funding went into office, computing, and accounting machines.

Large increases occurred in communication equipment and electronic components and in drugs and medicines. Venture capital investments in genetic engineering companies rose from $1 million in 1975 to $35 million in 1980. (See pp. 102-104.)

- The increasing interdependence of industry and university research is seen in the 29 percent increase from 1973 to 1980 in journal articles jointly written in both sectors. This increase was particularly great in physics. In terms of the extent to which authors in one sector cite the papers of authors in the other sector, industry depends much more on research done in universities than universities depend on industry. In physics, however, the predominant influence is from industry to university. (See pp. 107-108.)

In many ways, private industry is the most important sector of the American economy when assessing the status of American science and technology. About 70 percent of R&D activity in the United States, as measured by funds expended or by scientists and engineers employed in R&D, takes place in industry. Half of all R&D funds come from private industry.[1] R&D efforts in all sectors of the economy find their economically relevant outcome in industrial technology, which produces a stream of innovations, i.e., new and improved products, processes, and services that benefit the entire economy.

Federal policy areas that may have a direct impact on industrial R&D and innovation include: overall fiscal and monetary policy as it affects the predictability of economic trends and the cost of capital; changes in patent policy and other incentives to stimulate private returns to R&D and innovation; support of research and advanced graduate work in institutions that train engineers and technical personnel; and government procurement criteria and practices.[2] The administration has sought to encourage innovation in several of these ways, as will be discussed later in this chapter. One principal initiative has been in tax policy, particularly the Economic Recovery Tax Act of 1981. To the extent that tax policy contributes to economic growth and price stability in general, it reduces investment uncertainties and thereby encourages private investment in research and development and other phases of innovative activity. To the extent that it encourages capital investment, it influences the rate of introduction and diffusion of those technologies that are embodied in new plant and equipment. To the extent that it provides special allowances for increased R&D expenditures, it fosters company funding of R&D inhouse and in universities. To the extent that it is consistent, it reduces investment uncertainty.[3]

This chapter presents and discusses current data that bear on these policy concerns. The first section deals with issue areas that specifically relate to scientific and engineering personnel in industry, and the second with funding for R&D in industry. Data on the current level of innovativeness of U.S. industry are sparse, but various aspects of the subject are discussed in sections on patenting, productivity, and progress of specific technologies. A new section considers the resources and innovative outputs of high technology small business. The last section outlines the mutual dependence of the industry and university sectors in the R&D that leads to innovation.

SCIENTISTS AND ENGINEERS IN INDUSTRY

Business and industry is the largest employer of both scientists and engineers. In 1981, over two-fifths of all scientists (729,000) and more than three-quarters of all engineers (1.1 million) were employed in this sector. The number of scientists and engineers in industry has risen steadily between 1976 and 1981, from about 1.3 million to almost 1.9 million. (See appendix tables 4-1 and 4-2.) Despite the recent increase in the demand for engineers, employment of scientists, paced by the increase of computer specialists, grew at twice the rate of engineers (70 percent vs. 35 percent) during the 5-year period.

Employment of scientists and engineers in industry increased much more rapidly than total industrial employment. While scientist and engineer employment was up about 47 percent over the 1976-81 period, total industrial employment was up only about 15 percent.[4] The more rapid increase in S/E employment results from two major factors: the relative concentration of scientists and engineers in those industries (generally high technology) where overall employment is increasing rapidly; and a change in the occupational mix of industrial employment. Recent emphasis on increasing defense expenditures, relatively high levels of R&D expenditures, efforts to increase the competitiveness of U.S. industries, and technological change suggested that employment in science or engineering would increase at a faster rate than overall industrial employment.

Most engineers are employed in industry. The proportion ranges from almost 90 percent of all chemical engineers to 60 percent of all civil engineers.[5] Growth in engineering employment between 1976 and 1981 (35 percent) was paced by above average increases in the employment of civil (up 76 percent) and electrical (up 53 percent) engineers. Over one-quarter of the total growth in engineering employment was accounted for by the rise in the number of electrical engineers.

Industry's needs for scientists are concentrated in relatively few fields. (See figure 4-1.) Over 40 percent were computer specialists, and another 17 percent were physical scientists, primarily chemists. In contrast, only 7 percent were

[1]See ref. 112, tables 1 and 14. Industry is defined to include manufacturing plus those nonmanufacturing sectors in which R&D is conducted or financed.

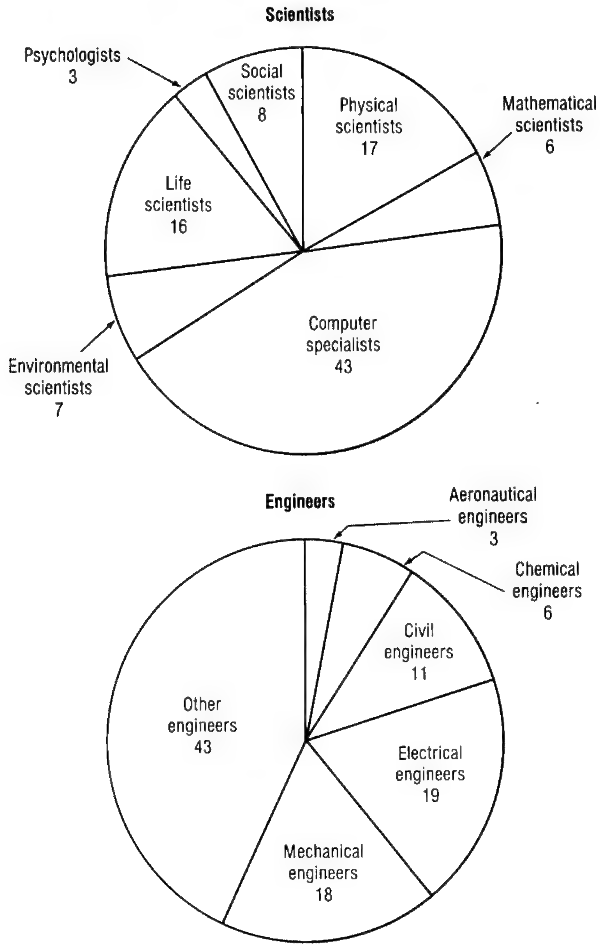
[2]General discussions of current policy problems relating to industrial innovation can be found in refs. 113, 114, 115, 116, and 117.

[3]On the effects of tax policy on innovation, see refs. 119, 120, and 121.

[4]See ref. 1.

[5]Ref. 148.

Figure 4-1
Percent distribution of scientists and engineers in industry by field: 1981



See appendix table 4-2.

Science Indicators—1982

mathematical scientists, and about 3 percent were psychologists. The importance of business and industry in providing employment opportunities for scientists varies considerably by field. This sector employs about 75 percent of all computer specialists and over 60 percent of all chemists. On the other hand, only about 24 percent of all social scientists are employed in business.[6]

Doctoral S/E's in Industry

Although educational institutions continue to be the major employers of doctoral S/E's, there has been a steady shift of job opportunities away from academia and toward industry. Employment of doctoral S/E's in industry increased at an average annual rate of 8 percent between 1973 and 1981, while overall employment of doctoral S/E's increased at an annual rate of 5.7 percent. As a result of this more rapid growth, industry's share of employment of all doctoral S/E's rose from 24 percent in 1973 to 29 percent in 1981.[7]

The doctoral intensity (the ratio of S/E's with doctorates to all S/E's) of the industrial work force declined slightly to about 5 percent between 1976 and 1981. The employment growth of doctoral scientists in industry fell short of total science growth in this sector. In 1981, slightly over 9 percent of the industrially employed scientists held doctorates, down from about 10.5 percent in 1976. The doctoral intensity of engineering employment in industry remained relatively stable at almost 3 percent.

There was significant variation in S/E doctoral employment growth by field. Between 1979 and 1981, employment in the physical, environmental, mathematical, and life sciences showed below average growth rates while above average growth was posted by computer specialists, social scientists, and psychologists. Since 1973, more than one-fifth of the total increase in the employment of doctoral scientists in this sector was accounted for by psychologists, reflecting in part industry's increasing concern for human resource development.

The proportion of all doctoral scientists and engineers employed in industry provides a rough indicator of this sector's importance in providing job opportunities. In general, industry is a less important source of job opportunities for doctoral S/E's than for those at lesser degree levels. This proportion varies considerably between engineers and scientists and among science fields. (See appendix table 3-11.) Industry employed over half of all engineers, chemists, and computer specialists at the doctoral level. However, only about one-quarter of all doctoral scientists were employed by industry.

Almost one-third of the doctoral S/E's in industry in 1981 were engineers, the largest proportion being electrical (20 percent) and chemical (17 percent) engineers.

Recent S/E Graduates in Industry

The increasing importance of industry as a source of job opportunities is corroborated by statistics describing the flow of recent S/E graduates into the economy. Increasing proportions of these new graduates are finding industrial employment. (See figure 4-2.) The proportion of recent graduates entering industry varies substantially both by degree level and by field.

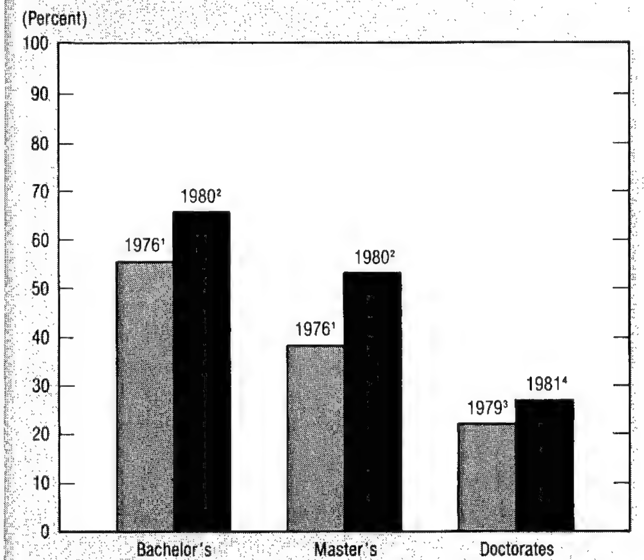
At the baccalaureate level, almost two-thirds of those receiving S/E degrees in 1978 and 1979 were employed by industry in 1980. This proportion has increased substantially since 1976 when a little over half of the 1974 and 1975 graduates were working in the business sector. Engineering graduates accounted for roughly half of the increase of new S/E graduates in this sector. Another one-quarter was accounted for by computer science and environmental science graduates. Only the number of mathematical science graduates going into industry decreased, reflecting primarily the rising numbers working as computer specialists rather than a decline in employment in this sector.

The shift into industry of new master's degree recipients was even more prominent. Between 1976 (1974 and 1975 graduates) and 1980 (1978 and 1979 graduates), overall

[6]Ref. 148.

[7]See ref. 2.

Figure 4-2
Proportion of recent science and engineering degree recipients finding employment in industry, by degree level



[1]1974 & 75 graduates.
[2]1978 & 79 Graduates.
[3]1977 & 78 graduates.
[4]1979 & 80 graduates.
See appendix table 4-3.

Science Indicators—1982

employment of these master's degree recipients grew less than 1 percent, while their employment in industry rose almost 40 percent. As a result, 52 percent of the 1978 and 1979 graduates were working in this sector in 1980, up from 38 percent in 1976 (1974 and 1975 graduates). About 30 percent of the overall increase was accounted for by engineers. Graduates with degrees in four science fields accounted for between 10 percent and 16 percent each of the overall increase: computer specialties, environmental and life sciences, and psychology.

The proportion of new doctoral S/E's going into industry was lower than at other degree levels. In 1981, slightly over one-quarter of the 1979 and 1980 graduates were in this sector. However, there has been some shifting of new doctorates toward industrial employment. In 1979, only about one-fifth of the 1977 and 1978 graduates were in industry.

Shifts in S/T Activities

Since the industrial sector drives a significant portion of the Nation's science and technology (S/T) effort, the work activities of S/E's in industry (R&D, production, etc.) are a direct indicator of the character of U.S. science and technology. In addition, because innovation depends in part on R&D, the number and proportion of S/E's in R&D may be a leading indicator of the Nation's overall innovative efforts.

There has been little change in the distribution of work activities of S/E's in industry between 1976 and 1981. (See appendix tables 4-1 and 4-2.) The greatest proportion continues to be engaged primarily in performing R&D, especially development. Significant shares are also found working in management (including management of R&D) and production/inspection (including quality control).

The largest growth was experienced by those scientists and engineers working in production and related efforts, including inspection. In 1981, almost 326,000 S/E's were primarily engaged in such efforts, up 63 percent since 1976 and over 8 percent since 1980. Engineers were the major impetus behind this growth; they accounted for almost 70 percent of the 1976-1981 increase. Increasing employment in these activities reflects the added emphasis industry is placing on improving productivity and quality control and on international competitiveness of U.S. firms.

Primary work activities differ significantly between scientists and engineers. While about one-half of industrially employed engineers work in development or production, the largest numbers of scientists report that they work in a combination of activities involving reporting, statistical, and computing work.

Regardless of field, many industrially employed scientists and engineers (about 30 percent) are in research and development. An additional 8 percent are working primarily in R&D management. More than four-fifths of those primarily engaged in R&D (excluding management) were in development with most of the remainder in applied rather than basic research. Development is the domain of engineers. They outnumber industrially employed scientists by 4 to 1 (350,000 to 93,000) in this activity. Among scientists in development, over half were computer specialists. Research, on the other hand, is the domain of scientists. In 1981, there were about twice as many industrially employed scientists (63,000) as engineers (36,000) in research.

Industrially employed doctoral scientists and engineers are more likely than those with lesser degrees to work in research and development. (See figure 4-3.) The proportion performing R&D in 1981 (44 percent) was the same as in 1973,[8] but up substantially from 1979 (37 percent). Other frequently reported primary responsibilities of those with doctorates are management of R&D (almost 19 percent) and sales and professional services (12 percent).

Between 1973 and 1981, the fastest growing primary work activities of doctoral S/E's were development and production, up at annual rates of approximately 10 percent and 12 percent, respectively. Primary activities differ between doctoral scientists and doctoral engineers. (See figure 4-3.) Doctoral scientists are highly concentrated in research (basic and applied), while doctoral engineers are found most often in development.

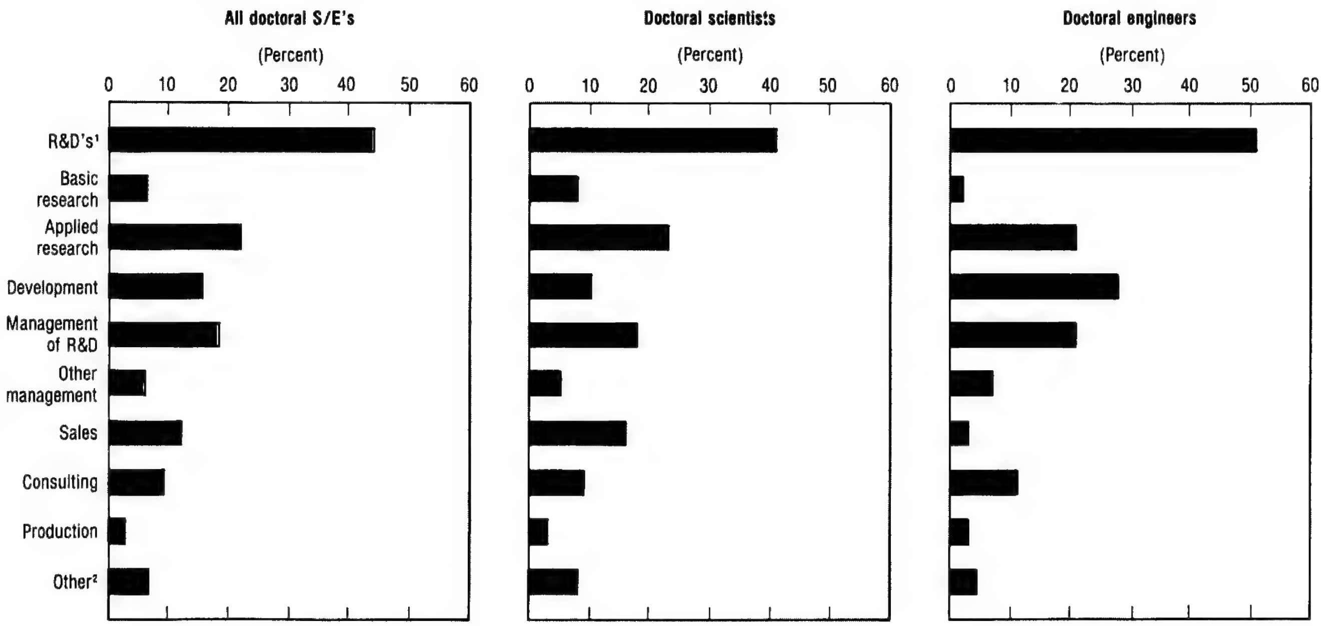
Concentration Ratios and Technical Support

A relative shift of resources from primary activities (such as agriculture and mining) to tertiary activities (such as services) has been occurring in the United States and in other advanced industrial societies for a considerable period of time. This shift reflects such factors as changes in consumer demand, government policy, patterns of foreign trade, and technology. These changes affect the employment demand for scientific

[8]Ref. 148.

Figure 4-3

Distribution of primary work activities for doctoral scientists and engineers in industry: 1981



[1]Excludes management of R&D.

[2]Includes teaching, reporting, statistical work, computing; other, and no report.

Based on appendix table 4-4.

and technical personnel and can result in redistribution of this demand by field, degree level, and type of work.[9] A large part of private industry's demand for scientific and technical personnel is still concentrated, however, in the manufacturing sector. In 1980, manufacturing employed less than 30 percent of all workers in private industry, but provided jobs for almost 60 percent of the engineers and 40 percent of the scientists. Between 1977 and 1980, overall employment growth in manufacturing amounted to less than 3 percent. Despite this slow rate of growth, however, the number of S/E's increased by about 20 percent.[10]

The increasing concentration of scientific and engineering personnel within the manufacturing sector is the result of changes in product mix which favor the S/E-intensive high technology industries, as well as changes in the staffing requirements of older, more mature industries. High technology industries that manufacture computers, semiconductors, microprocessors, robots, and other state-of-the-art electronic equipment are expected to continue their rapid expansion in the years ahead, especially in light of the planned defense buildup. Scientists, engineers, and technicians are critical to the research and product development activities which are essential to insure competitiveness and growth of these industries.[11]

Unlike high technology industries, mature industries, such as those manufacturing steel and automotive products, are suffering the effects of falling output levels due to aging capital stock.[12] Despite this poor economic performance and declining employment levels, the employment of scientists, engineers, and technicians in these industries has remained stable or even increased, indicating a change in staffing patterns favoring these skilled personnel. These changes are, in part, the results of continuing efforts to increase the productivity, efficiency, and competitiveness of older industries by incorporating major technological innovations in the production process. As the economic climate improves, the demand for S/E personnel can be expected to increase.[13]

Of those engineers not in manufacturing industries, significant numbers were employed in engineering and architectural service firms as well as by transportation, communication, and public utilities firms. In contrast to engineers, scientists (especially computer specialists) are concentrated in nonmanufacturing industries, primarily in those providing services such as computer and data processing activities. Other scientists are frequently found in manufacturing, particularly in chemicals and related fields.

The concentration of S/E's in a relatively small number of industries is the result of either the concentration of industrial activity in these industries, or the fact that their industrial technology requires a relatively large number of employees with S/E skills. One way to determine the relative effect of these two determinants is the use of "concentration

[9]See ref. 3.

[10]See ref. 4.

[11]See ref. 5.

[12]See ref. 6.

[13]See ref. 118.

ratios" for each industry, relating that industry's share of S/E employment to its share of total S/E and non-S/E employment. A ratio close to unity implies that S/E employment is primarily the result of industrial activity (reflected by total employment). A ratio greater than unity implies that these industries are relatively technologically intensive. (See figure 4-4.)

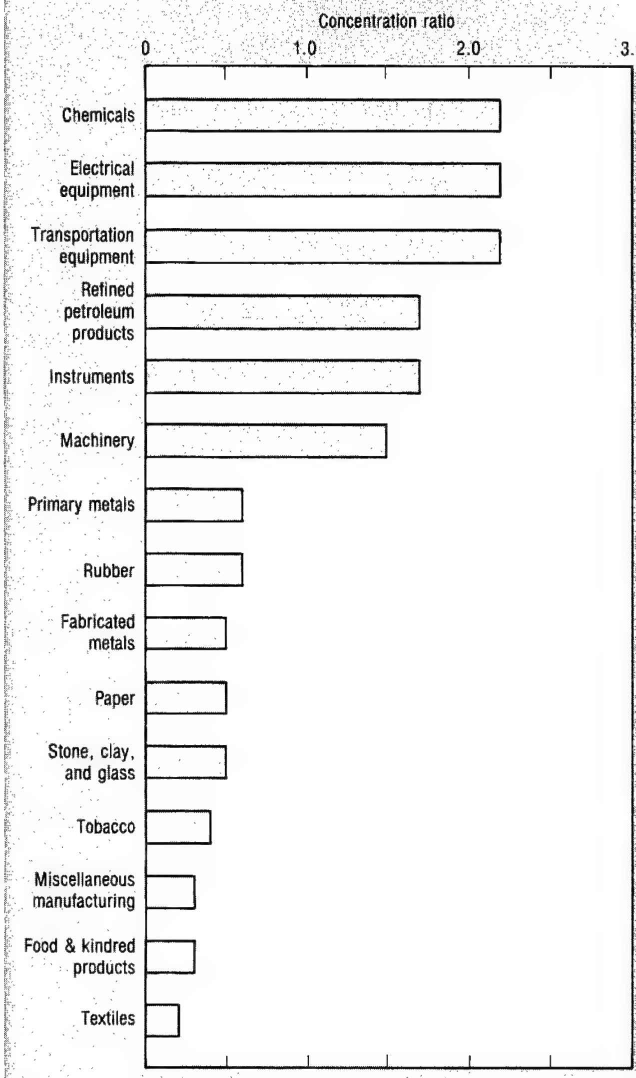
In addition to scientists and engineers, the private sector employs over 1 million S/E technicians, including drafters and computer programers.[14] The ratio of technicians to scientists and engineers ("technical support ratio") can be used to measure the amount of technician support provided scientists and engineers. Technicians are generally less skilled and are used directly or indirectly to support S/E's in every phase of their work. The technical support ratio for the private sector was 0.90 in 1980, meaning that for every 100 scientists and engineers, there were 90 technicians. The ratio varies widely among industries, ranging from 3.70 in "all other services" to 0.47 in transportation equipment. On the average, manufacturing industries have lower technical support ratios than nonmanufacturing industries. The wide variation in technical support ratios among industries (summarized in table 4-1) is the result of several factors including: the technology of the industry; the substitutability of technicians with other occupations including S/E's; and the relative costs of S/E's vs. technicians.

Selected S/E Related Issues

The industrial sector faces a number of issues relating to scientists and engineers. They include recent shortages of S/E personnel in several fields, skill obsolescence caused by the rapid pace of technical change in several industries, and changes in mandatory retirement laws.

Hiring and recruitment of new S/E graduates is a good indicator of general market conditions for scientists and engineers. In late 1981, a survey of management personnel[15] was conducted to assess the market conditions for these new graduates.[16] In spite of an economic slowdown in 1981, demand in that year was strong for new graduates in engineering, systems analysis, computer science, and earth science, with substantial shortages reported for most engineering fields and computer science. At the start of 1982, however, there were indications that the demand for scientists and engineers was not only slackening, but possibly was exceeded by supply. A survey[17] of industrial employers of large numbers of S/E's was conducted in late summer 1982. In the survey, respondents reported the most difficulty in hiring electrical engineers with master's degrees. However, they reported that it had become easier to hire "new entrant" scientists and engineers in all fields in 1982 compared to 1981. Of the firms reporting that finding new S/E entrants had become easier, fully 90 percent cited general economic conditions, rather than specific industry-related problems or increases in the supply of new workers, as the reason for the change in labor-market conditions.

Figure 4-4
Concentration ratios[1] of scientists and engineers in selected manufacturing industries: 1980



[1]A concentration ratio relates each industry's share of science and engineering employment to its share of total (S/E and non-S/E) employment.
See appendix table 4-5. Science Indicators—1982

A second major issue relates to the need for increased training resulting from the rapid pace of technological change. To help address this issue, the National Science Foundation (NSF) sponsored a study of the processes used by employers and employees in computer manufacturing and other high technology industries to cope with technological change.[18]

Study results show that the computer manufacturing industry has provided considerably more formal and informal on-the-job training to its scientists and engineers than have other high technology industries. The study shows that nearly one-half of the S/E's in the computer industry received

[14]See ref. 3.
[15]See ref. 6.
[16]See chapter on Scientific and Engineering Personnel for an overview of labor market conditions for all scientists and engineers.
[17]See ref. 9.
[18]See ref. 7.

Table 4-1. Ratio of technicians to scientists and engineers in private industry by selected industry: 1980

Industry	Ratio
Total, private industry	0.90
Manufacturing total	.80
Primary metals	.82
Fabricated metals	1.04
Machinery	1.10
Electrical equipment	.74
Transportation equipment	.47
Instruments	.94
All other durable goods	1.23
Chemicals	.62
Petroleum refining	.49
All other nondurable goods	1.01
Nonmanufacturing total	1.09
Crude petroleum and natural gas extraction	.48
Other mining	.62
Construction	.90
Finance, insurance and real estate	1.09
Business services	1.03
Miscellaneous services	1.23
All other services	3.70

SOURCE: National Science Foundation, *Scientists, Engineers, and Technicians in Private Industry: 1978–80* (NSF 80-320), p. 10.

Science Indicators—1982

formal training, and one-third received informal training. Other high technology industries typically provided between 15 percent and 30 percent of their S/E's with formal training and less than 20 percent with informal training.

With respect to changes in retirement legislation, employers indicated that very few scientists and engineers are postponing retirement. If they chose to retire later, they would relieve some of the need for new hires, but this does not seem to be occurring.

EXPENDITURES FOR R&D IN U.S. INDUSTRY

Expenditures in industry for innovation-related activities can serve as indicators of trends in the level of those activities. R&D is the one innovative activity for which extensive time-series data are available,[19] and R&D expenditures are a significant fraction of total innovation expenditures.[20] The two significant sources of R&D funds in industry are private industry itself and the Federal Government.[21] Figure 4-5 shows total R&D funds spent in industry, as well as funds separately contributed by these two sources.

In 1981, total R&D expenditures in industry (from both private and government sources) were about $52 billion or 72 percent of all the R&D expenditures in the United States. By this measure, most of the American R&D effort occurs in industry. This activity is especially oriented toward development, as is seen from the fact that industry does 86 percent of the development work reported in the United States.[22] As the figure shows, constant-dollar R&D funding has increased every year since 1960, except for the economic downturns of 1969-71 and 1974-75. From 1979 to 1981, such funding increased at a rate of about 6.5 percent per year. However, slower increases are estimated from 1981 to 1983.[23]

Trends in Company Funding

To understand these trends, it is necessary to consider separately the company and Federal components of industrial R&D funding. As the figure shows, company funding was less than half of all industrial R&D funding until 1967. While constant-dollar company funding has increased every year since that time, except for two recessions, Federal funding is far below the level of the mid-1960's. Most of the drop in Federal funding is due to the decline in funding from the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD).[24] The result is that industry now supports about two-thirds of all industrial R&D through its own funds.

While constant-dollar company funding increased by 7.3 percent per year from 1977 to 1980, and by 6.0 percent in 1981, increases of 4.9 percent and 5.2 percent are estimated for 1982 and 1983. This slight deceleration from the pace of the late 1970's is attributed to an unprecedented degree of economic uncertainty within industry, lower profit levels, and continuing high interest rates.[25] More generally, the level of company funding depends on a number of influences, including fluctuations in the economy and changes in the prices of labor and capital.[26]

A major influence on the distribution, and perhaps the amount, of company funding is thought to be Government regulation.[27] Recent estimates suggest that Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) regulations are the most significant.[28] Another reason for low increases in R&D expenditures by companies in

[19]Various studies in different countries show that R&D expenditures constitute between 15 percent and 50 percent of the total cost of innovation projects. For sources, see ref. 25.

[20]It should be noted that not all innovations depend on R&D. Many are made by engineers in operating units and other units outside R&D. See refs. 19, 22, 23, and 136. The relation between R&D and technological success is discussed in ref. 26.

[21]R&D data reported from industry sources in this chapter also include some funding from other non-Federal sources, such as State governments. However, the amounts from these other sources are small.

[22]See ref. 112, p. 27. For further discussion, see chapter on Support for U.S. Research and Development.

[23]For another estimate of 1982 and 1983 funding from both company and Federal sources, see ref. 150.

[24]See ref. 30, p. 26.

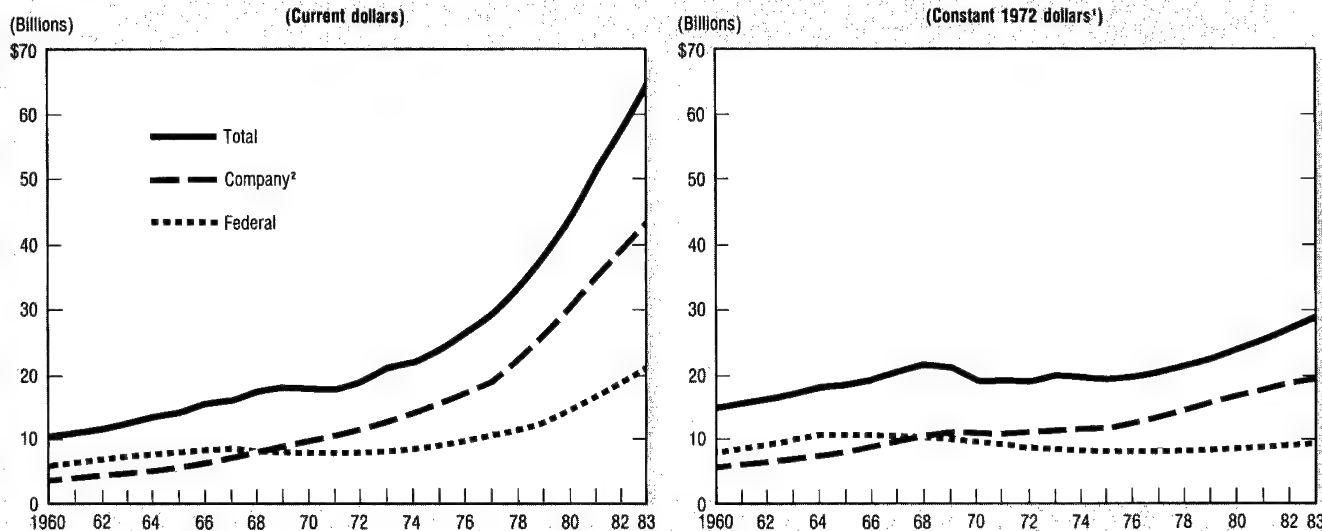
[25]See refs. 27 and 143.

[26]A quantitative study of the determinants of company R&D funding is ref. 28. One study has found that aggregate privately financed industrial R&D is positively dependent on total industrial output and on the age of the existing stock of R&D. It also depends significantly on the level of Government-supported R&D, particularly that performed in industry. The level of corporate taxation has a significant negative effect. Unlike privately fixed capital spending, R&D spending is not significantly affected by the level of unemployment, which suggests that R&D spending may be less cyclically sensitive than capital spending. See ref. 98.

[27]For a survey of this subject, see ref. 29.

[28]See ref. 30, p. 60.

Figure 4-5
Expenditures for industrial R&D by source of funds: 1960-83



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Includes all sources othern than the Federal Government.
Note: Preliminary data are shown for 1981 and estimates for 1982 and 1983.
See appendix table 4-6.

Science Indicators — 1982

some cases may be the perception that it is to a company's advantage to let its competitors take the risks.[29] If a competitor comes up with something, intensive copying can be relatively cheap.[30] If the competitor is small, it may even be possible to buy it. Company funding of R&D is further discouraged by professional management placing emphasis on the short run—the result of budgeting practices, the use of discounted cash flow analysis, and the measurement of performance in terms of return on investment. These practices lead to an emphasis on reliable results in the short term, whereas R&D generally is a long-term investment that is relatively risky in the short term.[31]

There are countervailing forces, however, that may encourage higher levels of company-funded R&D. One is the Economic Recovery Tax Act of 1981.[32] By providing a new 25-percent tax credit on incremental R&D expenditures by industry, it is expected to stimulate considerable corporate R&D spending in future years.[33] The need to keep up high levels of privately funded R&D can be seen in the fact that this is the type of R&D that leads to productivity improvement.[34] However, the rate of obsolescence in the benefits company-funded R&D brings to the performing company is found to be from 20 percent to 30 percent per year. As a result, most of the effects of private R&D outlays on the profits of the investing companies are exhausted within 5 or 6 years.[35]

Another recent development is the formation of research consortia made up of several companies in the same industry or in different industries to do research of mutual interest. Such consortia exist or are being formed in computer technology, communications, semiconductors, synthetic fuels research, aluminum refining, chemical pollution control, polymers, robotics, welding, and power generation, transmission, and distribution.[36] These developments are due in part to a clarification by the Department of Justice in 1980 of its position on cooperative ventures.[37] An especially important venture in this field is the Microelectronics and Computer Technology Corporation, a $50 million a year joint effort of 12 high-technology companies.[38]

Trends in Federal Funding

Government funding of industrial R&D has followed a much different trend. From its high point in 1966, constant-

[29]On these possibilities, see ref. 31.

[30]The classic study is reported in refs. 21 and 32. It found for the cases studied that the cost of imitating an innovation averages about 65 percent of the cost of first creating it, and takes about 70 percent of the time. The ease of imitation within a specific industry seems to have an important effect on the industry's market structure and concentration. Even patented innovations seem to be imitated frequently.

[31]See refs. 31, 33, and 34.

[32]See ref. 36.

[33]See ref. 37. Early studies of the effect of the Tax Act are reported in ref. 152 and ref. 153.

[34]See ref. 40.

[35]Another study finds a mean lag from R&D to peak profit return of 4 to 6 years, with substantial obsolescence of the R&D by the eighth year. See ref. 135.

[36]See refs. 122 and 163. Such consortia often also involve universities.

[37]See ref. 126. Legislation has been proposed (S. 2714 and S. 2717) to help businesses obtain from the Department of Justice a clear picture of the antitrust implications of prospective R&D joint ventures.

[38]See ref. 151.

dollar Federal funding dropped an average of 5.3 percent per year to a low point in 1975. From 1975 to 1980 it rose by an average of 2.8 percent per year, but the 1981 increase was 7.3 percent. Further increases of 6.1 and 6.0 percent are estimated for 1982 and 1983. In 1979, 59 percent of Federal support for industrial R&D came from DOD, 14 percent from NASA, and 13 percent from the Department of Energy (DOE).[39] This support was highly concentrated by industry, with 49 percent going to the aircraft and missiles industry and 26 percent into the electrical equipment industry.[40] Defense has remained a major component of Federal support for many years, while the space program has declined substantially.[41]

The high level of industrial R&D done under DOD and NASA sponsorship includes significant levels of independent R&D (IR&D). Industrial contractors selling goods or services to the Government are sometimes able to conduct a certain amount of R&D under their own initiative and control. By agreement with the sponsoring agency, a portion of the cost of IR&D is recovered by the companies through overhead charged to the agency. This funding is reported as company-supported R&D. In 1979, for example, DOD reimbursed $715 million to major contractors, which is 8.9 percent of its direct R&D support to industry. In that year, NASA reimbursed $54 million, or 3.0 percent of its direct R&D support. In 1981, DOD's reimbursement is estimated at about $1 billion and NASA's at about $65 million.[42]

The administration is planning for roughly an 8 percent annual growth in real military spending from 1982 to 1987.[43] This buildup should especially affect the durable goods sector, where real purchases of defense durables (R&D and procurement of major weapons systems) will grow at an estimated rate of 16 percent annually, a larger increase than during the peak years of the Vietnam buildup.[44] As far as R&D is concerned, the aircraft and missiles and the electrical equipment industries should be especially affected. This buildup produced a larger percentage increase in Government funding than in private funding for industrial R&D in 1981, for the first time since the early 1960's, and the Government's increase is estimated to be larger for 1982 and 1983 also.

The administration's policy is to stimulate private sources of funding by tax incentives, accelerated depreciation schedules, regulatory relief, and general improvement in the economy. A Federal funding role is seen in civilian-oriented basic research and in those areas of applied research and development that pertain to defense, space, or particular aspects of the regulated nuclear industry, where the Government is the primary customer for the goods or services to be developed.[45]

The effects of Government support of industrial R&D have been extensively studied. Its most general and pervasive effect seems to be that in the aggregate it stimulates private R&D spending.[46] The reason seems to be that Government-financed R&D creates promising opportunities for additional private R&D investment in industry.[47]

R&D Expenditures in Individual Industries

R&D is much more important to some industries than to others, and some industries contribute far more than others to the total of industrial R&D. This can be seen from figure 4-6, which shows the levels of R&D funding from all sources, from 1960 to 1981, for the eight industries in which the most funding occurs.[48] The aircraft and missiles industry alone accounts for 23 percent of all industrial R&D, while electrical equipment accounts for another 20 percent.[49]

Some industries have especially high levels of R&D funding as a percent of their net sales, and can be considered particularly R&D intensive. This is true in particular for office, computing, and accounting machines, aircraft and missiles, communication equipment, electronic components, drugs and medicines, and professional and scientific instruments.[50] Some of these are among the industries that have seen rapid increases in R&D in recent years. For example, office, computing, and accounting machines R&D increased 7.6 percent per year in constant dollars from 1978 to 1980. (See appendix table 4-7.) This is the largest component of nonelectrical machinery R&D. Communication equipment R&D rose 9.4 percent per year, while electronic components rose 16.5 percent. The increase for scientific and mechanical measuring instruments, a component of

[39]After rising 3.2 percent from fiscal 1979 to 1980 and 2.0 percent from fiscal 1980 to 1981, constant-dollar Federal obligations for industrial R&D rose by an estimated 8.2 percent from fiscal 1981 to 1982 and by an estimated 8.4 percent from fiscal 1982 to fiscal 1983. Of the fiscal 1981 obligations, 67 percent were obligated by DOD and 21 percent by NASA. See ref. 144, pp. 74, 75, 95, and 99.

[40]See ref. 30, p. 26.

[41]Further discussion of Federal R&D policy can be found in the chapter on Support for U.S. Research and Development.

[42]These numbers do not include the closely related expenditures for bid and proposal (B&P) preparation, which are also reimbursed to the contractor. For a more extensive discussion, see ref. 79, pp. 68-69, and ref. 130. Data are from refs. 131 and 132. The effect of IR&D on private company R&D expenditure is studied in ref. 40.

[43]See ref. 145.

[44]See ref. 35, pp. 85-86.

[45]See ref. 37. A historically oriented study of the policy problems involved in Federal support of civilian sector R&D is ref. 38. Also see ref. 39.

[46]See refs. 40 and 42. For the effect on productivity, see the section of this chapter on productivity.

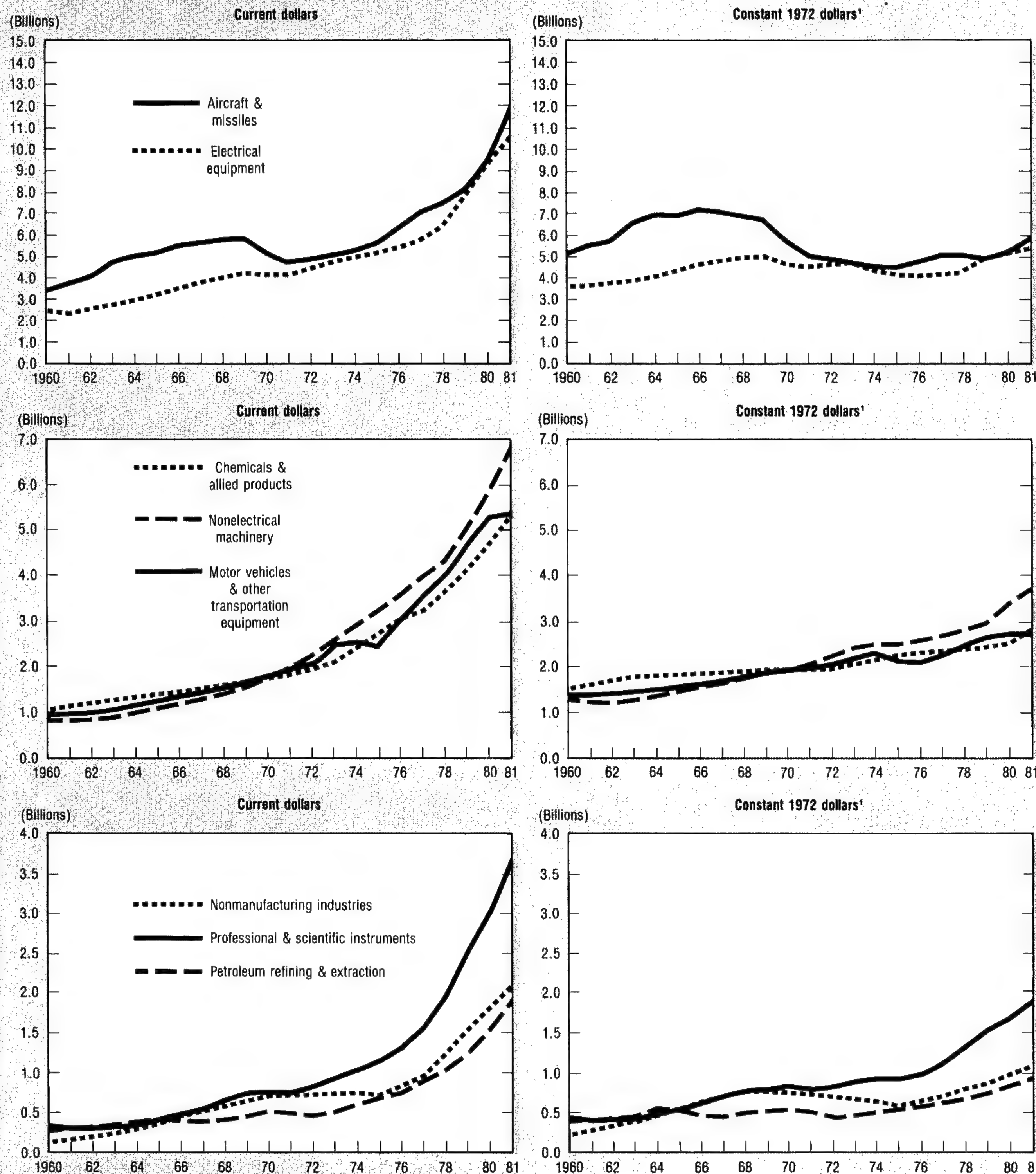
[47]Estimates of this effect range from 8 to 17 additional cents of private expenditure per dollar of Federal outlay with a time lag of 3 or 4 years. One study (ref. 41) has found that Government funding of research displaces private research funding in favor of more development funding. Also see refs. 43 and 99. Contract R&D performed in industry stimulates on average about 27 cents of private spending per dollar of Government expenditure. See ref. 40.

[48]For the remaining industries, which account for 9 percent of total industrial R&D expenditures, see appendix table 4-7. Industries are classified by enterprise in terms of the Standard Industrial Classification (SIC) for establishments. Each corporation responding to the survey is assigned to a single SIC. Other sources of R&D data by individual industry are the Federal Trade Commission's Line of Business Reports and the 10K forms that corporations file with the Securities and Exchange Commission, as reported annually in the first July issue of *Business Week*. The latter reports R&D expenditures by selected individual companies but does not aggregate them in terms of the SIC.

[49]See appendix table 4-7. R&D expenditures are also concentrated in terms of performing companies. For example, in 1980 four companies accounted for 18 percent of all industrial R&D expenditures, and four accounted for 24 percent of company-supplied funds. See ref. 17, table 17.

[50]See ref. 17, table B-19. A high correlation is found between R&D expenditures in a company and company sales. See ref. 70.

Figure 4-6
R&D expenditures by selected industries



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Preliminary data are shown for 1981.
See appendix table 4-7.

Science Indicators—1982

professional and scientific instruments, was 24.6 percent per year from 1978 to 1981. Other large increases were in radio and television receiving equipment (53.3 percent per year from 1978 to 1981), petroleum refining and extraction (11.6 percent per year), and ferrous metals and products (11.5 percent per year). The increase in aircraft and missiles was quite low from 1978 to 1980 (1.4 percent per year), but from 1980 to 1981 the increase was 16.2 percent. In the case of drugs and medicines, the increase was only 5.4 percent from 1978 to 1981, less than the average for all industries. Among the large R&D performers, motor vehicles actually dropped in R&D expenditure (0.8 percent from 1978 to 1981). Among the smaller R&D performers, lumber, wood products, and furniture had no change in its R&D efforts from 1978 to 1981.

The first of these industries—office, computing, and accounting machines—may see slower spending for R&D and capital equipment in the immediate future, in response to uncertainties about the U.S. economy, the depressed state of many European economies, and the relative strength of the U.S. dollar.[51] On the other hand, computer and software suppliers expect to benefit from the accelerated depreciation provisions of the Economic Recovery Tax Act of 1981. The R&D provisions may stimulate both domestic corporate and university research in future years, as well as ease the tax burden of U.S. firms with foreign operations.[52] In the longer run, rapid technological changes and intense foreign and domestic competition suggest that additional R&D investments will have to be made, especially in the areas of micro- and minicomputers.[53] These funds will come mostly from private sources, since the nonelectrical machinery industry (which includes computers) receives a relatively low share of its R&D funds from the Government. (See table 4-2.)

The communication equipment and electronic component industry is closely related to the computer industry. In fact, many computer companies are now performing their own semiconductor research in order to custom design integrated circuits to their own needs.[54] Technological competition in this industry is especially keen, especially with the Japanese. While parity has been achieved in some areas, the United States evidently retains the lead in computer-aided design and microprocessor design.[55] Competition in random-access memory technology requires U.S. companies to put considerable R&D funding into this field.[56] Semiconductor R&D is also funded in part by the Government. The Department of Defense is supporting a major effort on very high speed integrated circuits. This program is expected to be funded at about $500 million through Fiscal Year 1985, a spending level intended to exceed the Japanese joint government/industry effort.[57] The communication equipment industry sells a large portion of its total output to the Government and can expect to benefit from increased defense expenditures.[58] In spite of this, since 1971 the electrical equipment industry, which has communicating equipment as its largest R&D component, has substantially decreased its dependence on Government funding. (See table 4-2.) Some of this is probably due to increased private efforts in telephone equipment.[59] In 1981, the telephone industry spent almost $1.6 billion for R&D programs in such areas as digital technology, microelectronics, lightwave communication, and software.

The scientific and mechanical measuring instruments industry depends on activity in the equipping of laboratories for research, development, and medical and industrial testing. R&D in this industry should continue to grow with the aid of the Economic Recovery Tax Act, which encourages additional R&D expenditures in the customer industries.[60] Moreover, the rate of equipment obsolescence has been increasing. R&D is becoming more capital intensive, with individual researchers requiring larger amounts of more sophisticated equipment. The boom in the health care field also stimulates the demand for new instruments. Finally Japanese competition is spurring American R&D in this field.[61] Since R&D in this industry receives relatively little support from the Government (table 4-2), these are essentially private R&D efforts. In fact, company funding in this industry increased threefold from 1971 to 1980.

The aircraft and missiles industry depends more on Government funding for R&D than does any other industry (table 4-2), and in fact is the only industry receiving more than half of its funding from the Government. In recent years, Government outlays were reduced and company funding, though it increased, was not enough to make up the difference. This industry benefits from NASA, DOD, and Department of Transportation (DOT) research support, whether the funding goes directly to the industry or to universities and colleges, private institutions, and supplier industries. Analysts are concerned that instability and uncertainty of Federal funding may have impaired the technological competitiveness of the U.S. aerospace industry.[62] However, growing expenditures for military equipment in 1983 and afterward are expected to offset the projected decline in demand for civilian aircraft and to strengthen the industry. The administration has announced a policy aimed at strengthening U.S. research and technology production in defense and civil aviation.[63]

The drugs and medicines industry is the industry with the highest portion of privately supported R&D. (See table 4-2.) While growth in R&D funding has been only at the average rate for all industries in the last few years, considerable increases can be expected in future years. Recent major biological and medical breakthroughs and marketing opportunities in new technologies are expected to stimulate additional R&D. Research and development will also be

[51]See ref. 44, pp. 77-78. The computer industry is one in which the international competitive position of the United States is outstanding. See ref. 45, p. 89, and ref. 47.

[52]See ref. 46, p. 227. For some industries, these benefits are modified by 1982 tax legislation.

[53]See ref. 27.

[54]See ref. 27. Captive companies account for 40 percent of domestic integrated circuit production. See ref. 45, p. 82.

[55]See ref. 45, p. 85, and ref. 44, pp. 74, 77.

[56]See ref. 46, p. 239.

[57]See ref. 149, p. F-2. For another estimate, see ref. 156, pp. 19-22.

[58]See ref. 46, pp. 233-235, and ref. 155, pp. 8-9.

[59]See ref. 46, pp. 228-231, and ref. 44, p. 79. R&D in the electronics industry is also discussed in ref. 48, pp. 288-290.

[60]See ref. 46, p. 272.

[61]See ref. 27.

[62]See ref. 46, p. 259; ref. 48, p. 298; and ref. 49, pp. 708-713, 717-725.

[63]See refs. 154 and 158.

Table 4-2. Federal funding as a percent of total R&D funding in selected industries: 1971 and 1981

Industry	Year 1971	Year 1981
All industries	42	32
Chemicals and allied products	10	7
Industrial chemicals	16	14
Drugs and medicines and other chemicals[1]	3	1
Petroleum refining and extraction[1]	3	7
Rubber products[1]	24	24
Primary metals	2	20
Ferrous metals and products[1]	1	25
Nonferrous metals and products[1]	3	12
Fabricated metal products	5	13
Nonelectrical machinery	17	11
Electrical equipment	51	38
Communication equipment and electronic components	54	34
Motor vehicles and other transportation equipment[1]	17	14
Aircraft and missiles	79	73
Professional and scientific instruments	22	17
Scientific and mechanical measuring instruments[1]	11	24
Optical, surgical, photographic, and other instruments[1]	25	12
Nonmanufacturing industries	64	42

[1] Data for 1981 are estimated.

See appendix table 4-8.

Science Indicators—1982

promoted by increased domestic and foreign competition. The tax credit for increased R&D expenditures in the United States and the recent shortening of the time required for FDA approval of new drugs are also thought to be stimulating the industry.[64] While an increased flow of new products is expected, some observers wonder whether the United States will continue to be on the leading edge of science in this area. Drug research has cost companies close to 50 percent of earnings over the past several years, and it is not clear that the rewards will continue to justify this level of expenditure.[65]

The motor vehicles and equipment industry has had a below average rate of increase in R&D expenditures in the last few years and is not expected to increase its R&D substantially in the near future. The industry is currently in a weakened condition because of its considerable loss of sales to foreign competition and a downtrend in demand due to poor economic conditions. The result has been a serious cash shortage. R&D is competing for fewer available funds, against such necessary expenditures as new equipment and engineering. In addition, close to half of the R&D budgets of most American automobile manufacturers are spent to meet Federal safety, emission, and fuel economy standards.[66] According to industry estimates, regulation increased the retail price of the average car in the recent past by more than $1,000.[67] The administration placed major emphasis on regulatory reform in the automobile industry assistance program announced in April 1981.[68]

Trends in Multinational Company Funding

Industry's investment in R&D from its own funds also includes the funds that American multinational corporations spend for the performance of R&D by their foreign affiliates. Some data on the amount of this investment are shown in figure 4-7. In current dollars, the amount of foreign R&D funded by U.S. industry increased by a factor of 2.4 from

[64]Recently, about 7 years have been required, on the average, from the time a new drug is first tested on humans to the time it is approved for marketing. Attempts to speed up the review process and give priority treatment to important new drugs have been able to cut a year or two out of this delay.

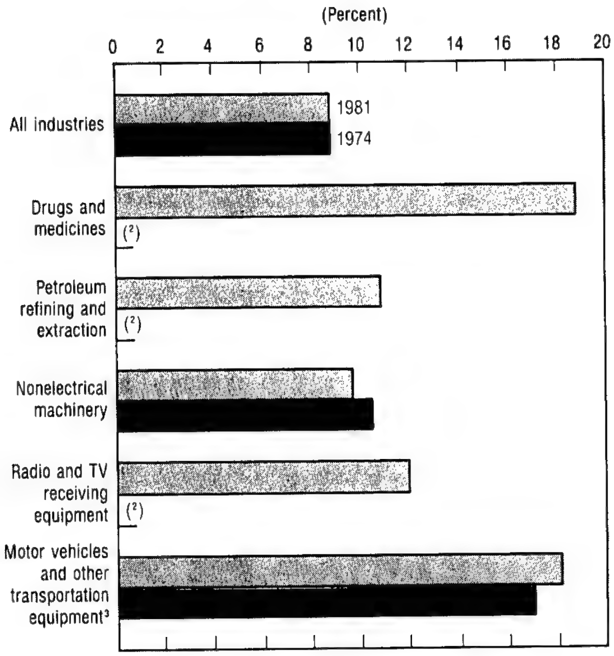
[65]For this industry, see ref. 27; ref. 147, pp. 77, 80; ref. 44, pp. 70, 74; ref. 46, pp. 132-137; and ref. 48, pp. 293-296.

[66]See ref. 48, p. 299.

[67]See ref. 46, p. 245.

[68]On this industry, see ref. 45; ref. 48, pp. 298-300; ref. 27; ref. 44, pp. 62-63; and ref. 46, pp. 242-253. Ref. 146 emphasizes the increasing importance of technological innovation to this industry.

Figure 4-7
Foreign-affiliate R&D as a percentage of company-funded[1] R&D for selected industries



[1]Includes all sources other than the Federal Government.
[2]Not available.
[3]Estimate shown for 1981.
See appendix table 4-9.

Science Indicators—1982

1974 to 1981.[69] It is now nearly 10 percent of private industrial R&D expenditures within the United States.[70] There is considerable concentration in terms of industries. Thus, in 1974 the motor vehicles and other transportation industry paid for 28 percent of all foreign R&D supported by U.S. companies, spending 17 percent as much for that purpose as it spent at home. Similar levels of expenditure are estimated for 1981. The drugs and medicines and other chemicals industry spent a comparable share of its R&D funds abroad in 1981. Other especially active industries are radio and TV receiving equipment[71] and petroleum refining.

These R&D investments roughly follow the pattern of total direct investments abroad. Direct investment by the manufacturing industries is dominated by the transportation equipment, chemical, and nonelectrical equipment industries, as is also the case with annual R&D funding abroad.[72] On the other hand, electrical equipment seems to have a higher share of R&D funding abroad than of total investment, and petroleum has a much lower share.

The high levels of foreign R&D in chemicals reflect in part the considerable foreign efforts of the drug industry.[73] Multinational corporations in this industry are well on the way to integrating their domestic and foreign R&D efforts, so that it is no longer true that a new drug is discovered, tested, and commercialized all within a single country. Instead, the discovery phase often involves collaboration among laboratories and researchers working for the same firm, but in different countries. Clinical testing also becomes a multicountry project, and often the later phases of drug development such as dosage formulation, do as well.[74] In addition, as a result of regulatory and pricing incentives, tax advantages, and market needs, U.S. companies are establishing laboratories and conducting more clinical research in those countries where they need to market their products.[75] Another possible influence on the amount of R&D performed overseas is tax policy. Industry representatives have complained that some provisions of the Federal tax code (which are temporarily suspended) penalize domestic R&D and indirectly encourage R&D performance abroad.[76]

Recent studies have shown that multinational companies with foreign subsidiaries that perform R&D have become an important channel of technology transfer. Foreign subsidiaries account for many more cases of technology transfer abroad than exports, licensing, and joint ventures do.[77] In some cases, this technology is leaked to foreign competitors. Still, the decision by U.S. firms to perform some of their R&D abroad also benefits U.S. technology in many ways. Some large U.S. companies would perform less R&D at home if they could not count on being able to transfer or use their technology overseas. Thus there would be less R&D to bolster U.S. domestic technology.[78]

A further benefit to the U.S. economy from the foreign R&D of U.S. multinationals is "reverse technology transfer." To an increasing extent, foreign subsidiaries are transferring technology back to their U.S. parents. As table 4-3 shows, this process has accelerated since 1965, so that in 1979 an estimated 47 percent of overseas R&D resulted in technologies transferred to the United States. In view of the

[69]These overseas expenditures are not included in the data reported on the preceding tables and figures. Data for more industries and years are shown on appendix table 4-9. Another source (ref. 55) gives $2.1 billion for total R&D expenditures abroad in 1977.

[70]A slight decline in foreign R&D spending was reported from 1980 to 1981, which runs counter to the steady increases of previous years. This decline may be due to changes in currency exchange rates unfavorable to the dollar, and also to a decline in foreign sales by U.S.-based multinationals due to the European recession. The motor vehicles industry seems to have had a significant decline in foreign R&D expenditure.

[71]The number on the table includes radio and television receiving equipment, but this is quite a small share of the total. See appendix table 4-7.

[72]See ref. 51 and appendix table 4-9. Direct investment is made up of U.S. direct investors' equity in, and outstanding loans to, their foreign affiliates. On U.S. direct investment abroad, also see refs. 52 and 55. On foreign investment in the United States, see refs. 53, 54, 56, and 129.

[73]By one estimate, drug industry spending abroad for R&D, in current dollars, grew at an average rate of 22 percent per year from 1970 to 1980, reaching $337 million in 1980. See ref. 46, p. 132.

[74]See ref. 57.

[75]See ref. 48, p. 296.

[76]See ref. 164.

[77]For this whole discussion, see refs. 57, 32, and 68. On the measurement of technology transfer, see refs. 59 and 60.

[78]In one study, the firms sampled reported that 30 percent of the anticipated returns from their domestic R&D projects were expected to come from foreign sources. Without these revenues, they would have spent an estimated 20 percent less on R&D. See ref. 32.

Table 4-3. Percentage of overseas R&D expenditure resulting in technologies transferred to the United States, by industry and size of firm: 1965–79

Industry or size of firm	1965	1970	1975	1979
Total	37	44	44	47
	By industry			
Chemical	2	22	30	49
Machinery	94	91	81	82
Electrical equipment	8	11	14	18
Instruments	83	85	87	87
Other	10	34	33	37
	By size of firm[1]			
Larger firms	38	46	45	46
Smaller firms	23	31	34	53

[1] Larger firms in this study are those with worldwide sales exceeding $2 billion in 1977; smaller firms are the others. This definition of small firms differs from that used elsewhere in this chapter.

NOTE: These data are based on a sample of overseas laboratories accounting for about 10 percent of all overseas R&D of American companies. Thus, they are subject to sampling errors.

SOURCE: Edwin Mansfield and Anthony Romeo, "'Reverse' Transfers of Technology from Overseas Subsidiaries to American Firms," University of Pennsylvania, 1983.

Science Indicators—1982

sharply increasing dollar amounts of foreign R&D in recent years (appendix table 4-9), technology transfer has increased considerably.

The increasing percentage of R&D expenditures resulting in reverse technology transfer reflects the fact that overseas laboratories are being transformed from organizations that simply service and adapt U.S. technology for foreign markets to organizations that are expected to produce technology for worldwide application. Laboratories of the latter kind are involved in more reverse technology transfer, as are larger laboratories and those devoting a large percentage of their R&D expenditures to research.[79] The average lag between the foreign and U.S. application of a technology has been sharply reduced in many industries, so that U.S. employment of the technology created by a foreign affiliate is almost immediate. In the electrical equipment industry, there is even some tendency for U.S. application to precede foreign application. The chemical industry (including drugs) is exceptional; there are still delays averaging a year in the U.S. application of foreign-originated drugs. This is evidently related to the FDA regulatory process.

Table 4-3 shows a large increase in reverse technology transfer in the chemical industry, perhaps because of drug companies' increasing use of foreign laboratories to develop products for the U.S. market. Other industries, specifically scientific instruments and nonelectrical machinery (including computers) have returned substantial amounts of their foreign-originated technology to the United States for many years. In most of the industries other than chemicals, the rate of reverse technology transfer depends much more on the nature of the laboratories, as described above, than on the nature of the industry itself. Smaller firms, some of which are ethical drug firms, are catching up with the large companies in the transfer of technology to the United States.

The nature of the transferred technology can be seen from appendix table 4-10, which divides the technologies transferred in 1979, according to table 4-3, into new or improved products or processes. New products are the most frequent by far in most industries, though product improvements dominate in the scientific instruments industry.

PATENTED INVENTIONS

One of the principal results of industrial R&D is the production of technical inventions, i.e., new or improved products or processes with some expected utility. Such inventions become publicly visible when the inventor applies for and receives a patent. Thus counts of patents serve as one indicator of R&D output and inventive activity. In addition, inventions are an input to later stages in the process of innovation in that they represent a pool of technological knowledge from which innovations may be produced. The analysis of patent information remains one of the most established, directly available, and historically reliable methods of quantifying the output of a science and technology system.[80]

Limitations on the use of patenting data should be recognized. Such data provide an aggregate indicator of invention, but do not identify the really important individual inventions.[81] In addition, some inventions are not patented because the inventing company prefers to retain the invention as a trade secret. In fact, some entire technologies, such as

[79]See ref. 68. These results are based on a sample of 29 overseas R&D laboratories of U.S.-based firms.

[80]See ref. 61.

[81]See ref. 62, p. 209. Recent efforts to identify important inventions by using patent files are reported in refs. 64 and 106.

living organisms and computer software, are not acceptable subjects for patenting.[82] The propensity to patent inventions varies from one industry to another, so that comparisons between industries should be avoided.[83] Finally, the patents that are granted represent inventions of widely different values, whether in technical, economic, or social terms. The value of an invention must depend on the values of the innovations to which it contributes, but these values are not known for the typical patent.[84] In using patenting statistics, one assumes that patents have the same value in all of the countries, time periods, etc., being compared. This can mean that the individual patents all have the same values, or that the distributions of values in the groups being compared are the same.[85]

Inventors and Owners of Inventions Patented in the United States

Figure 4-8 shows the number of patents granted in the United States to both U.S. and foreign inventors. Patent counts by date of patent grant are quite irregular from year to year, but the data show a clear upward trend from 1960 to 1971, with a drop thereafter. This drop is due to decreases in patenting by U.S. inventors, at the same time that foreign patenting in the United States increased.

The irregularity in patent counts by date of grant is due to the fact that there are fluctuations in the rate at which the U.S. Patent Office processes its backlog of applications, as well as in the rate at which it prints and issues patents after they are accepted.[86] These fluctuations can be removed from the data if one classifies granted patents in terms of the dates at which the inventors filed the original patent applications. The application date is, on the average, 2 or 3 years before the grant date, and is closer to the date at which the invention was actually made.[87]

In these terms, figure 4-8 shows that peak rates of patenting in the United States were reached in 1971 and 1974. A slight decline occurred from 1974 to 1979 (0.5 percent per year) but an increase (2.9 percent per year) occurred from 1979 to 1982, so that patenting reached new high levels in 1980, 1981, and 1982. The figure also shows that these trends are made up of quite different trends in patenting by U.S. inventors and foreign inventors. Foreign patenting has increased every year from 1965 to 1982, except for 1975. The average rate of increase has been 5.2 percent per year over the whole period. On the other hand, patenting in the United States by Americans peaked in 1969, and declined from 1969 to 1979 at an average rate of 1.7 percent per year. This decline has reversed since 1979; from 1979 to 1982, U.S. patenting increased by an estimated 1.5 percent per year. As a result, an estimated 42 percent of patent grants based on 1982 applications will be to foreign inventors.[88]

The rapid increase in foreign patenting does not necessarily imply that foreigners are rapidly becoming more inventive. An analysis of the output of foreign inventors must also consider their patenting in their own countries.[89] Foreign patenting in the United States depends not only on the inventive capacity of the source country, but also on its cultural and economic ties with the United States.

The decline in successful patent applications by Americans from 1969 to 1979, however, does seem to be a sign of declined inventive output. In some product fields, this decline may be attributed to a decreased propensity to take out patents for inventions.[90] However, since it occurs in nearly all product fields, some more general explanation, like a decline in inventive activity and output, seems to be required.[91] It can be seen more clearly in figure 4-9, which divides patents by U.S. inventors according to whether the patent owner is an individual, a Government entity, or a private corporation. Employees of corporations and Government laboratories commonly assign ownership to their employer for any patent received as a result of their employment activities. However, many other patents remain the property of the individual inventors.

Figure 4-9 again considers patenting both by date of grant and by date of application. In 1982, 71 percent of U.S.-origin patents granted came from U.S. corporations, while 25 percent came from independent individuals and 3 percent from Government agencies.[92] Thus, it is corporations that mainly determine U.S. patenting trends. In terms of application dates, corporate patenting declined 2.1 percent per year from its high point in 1969 to the low in 1979 and rose an estimated 1.7 percent per year from 1979 to 1982.[93]

Patenting in Individual Product Fields

Patenting by U.S. inventors sometimes follows quite different patterns in the various fields of technology. Information about these different fields can be helpful in

[82]Recent court rulings have opened the way for the patenting of some organisms. See ref. 107, pp. 2-3, 9-11. On the patenting of computer software, see ref. 104 and ref. 108, pp. 47-71, 126-156, where some data are discussed.

[83]See ref. 20 and ref. 72, which discuss industry structure and other influences on patenting rate. Also see ref. 63.

[84]See ref. 20.

[85]Comanor and Scherer (ref. 65) point out that the same assumptions about the constant distribution of quality are made, for example, when one uses a simple count of scientists and engineers, or research and development expenditures, as an index of innovative input. For a more thorough discussion of the limitations of patenting data as indicators of technical invention, see ref. 66, pp. 99-102; ref. 67; and ref. 137. Econometric studies with disaggregated data are able to cope with most of these problems.

[86]A delay of the latter kind was especially serious in 1979.

[87]According to ref. 136, about 9 months elapse, on average, between the conception of a patentable invention and application for a patent. A disadvantage of using counts of granted patents by application date is that the data are incomplete for the most recent years because many recent applications have not yet been processed. Estimates of the number of patents that will eventually be granted are shown on figure 4-8 for the years 1978-82. These estimates are based on the number of applications in those years and on average rates of approval of applications.

[88]Of the patents actually granted in 1982, 41 percent went to foreign inventors.

[89]See chapter on International Science and Technology.

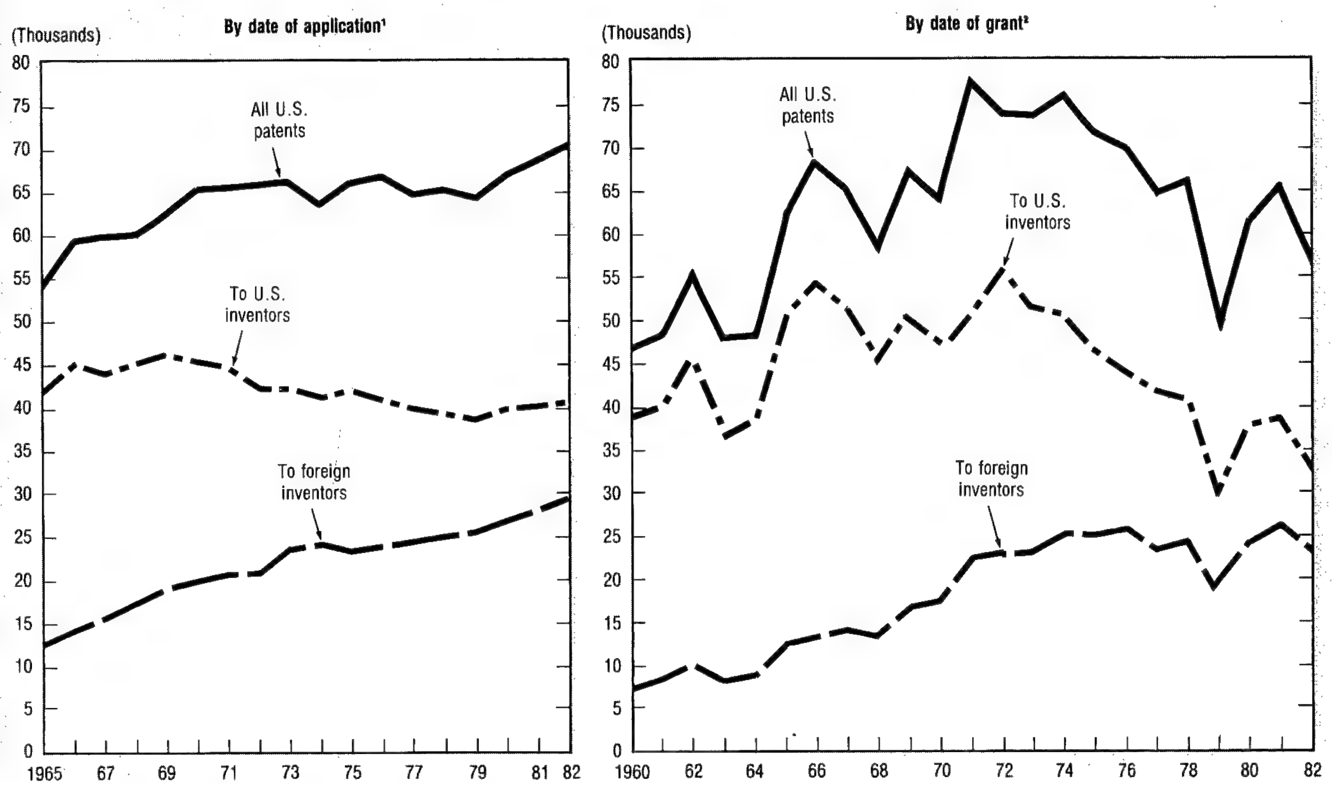
[90]See refs. 20 and 63, and ref. 38, pp. 72-74.

[91]Studies of this decline are reported in refs. 135, 138, and 139.

[92]The data include patents owned by universities with corporate patenting. However, the number of university-owned patents is quite small; by one estimate, 0.4 percent of corporate patents were really university-owned in 1974, and 1.1 percent in 1980. See ref. 69 and chapter on Academic Science and Technology.

[93]The curves for patenting by date of application are based on figure 4-8 and on the assumption that corporations and the other owners received constant shares of all U.S.-origin patents from 1978 to 1982.

Figure 4-8
U.S. patents granted, by nationality of inventor



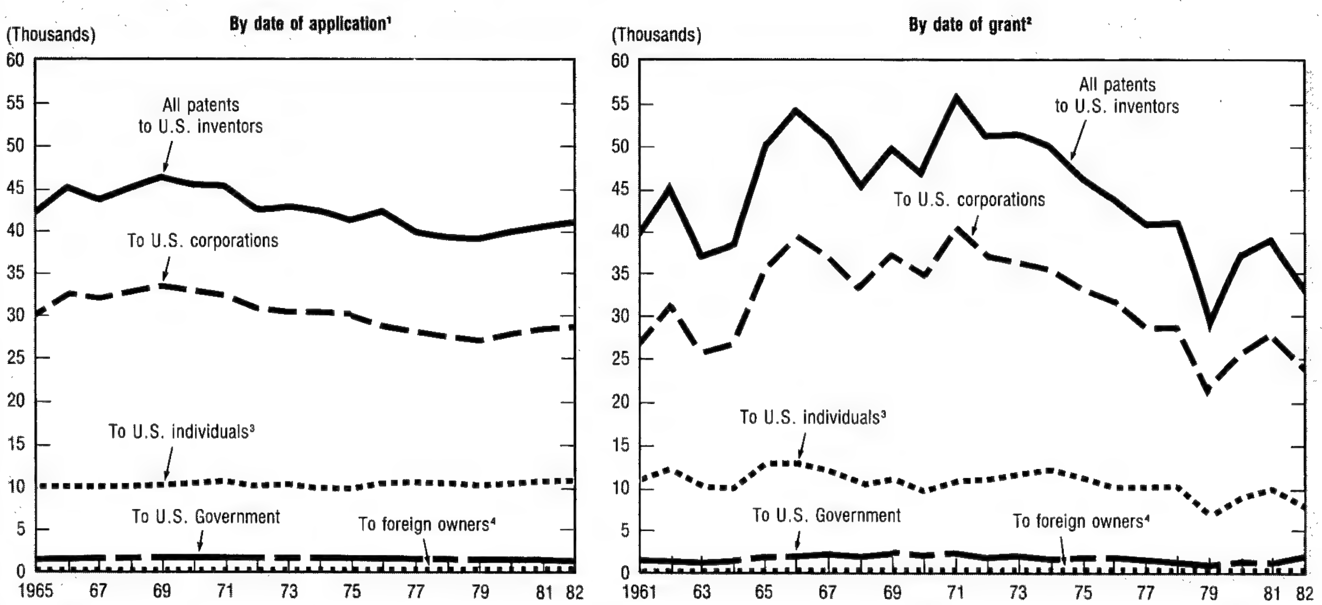
[1]Estimates are shown for 1978-82 for patenting by date of application.

[2]A smaller number of patents were granted in 1979, because of a lack of funds in the Patent Office for printing and issuing patents.

See appendix table 4-11.

Science Indicators—1982

Figure 4-9
U.S. patents granted to U.S. inventors, by type of owner



[1]Estimates are shown for 1978-82 for patenting by date of application.

[2]A smaller number of patents were granted in 1979, because of a lack of funds in the Patent Office for printing and issuing patents.

[3]Includes unassigned patents.

[4]Comprises patents assigned to foreign corporations, governments, and individuals.

See appendix table 4-12.

Science Indicators—1982

understanding overall trends in U.S. patenting. (See table 4-4 and appendix table 4-13.)

From 1971 to 1981, the rate of patenting dropped in almost every product field, so that the rate of patenting for all fields together decreased by an average 4.6 percent per year.[94] Only a few fields, which are all chemical-related fields, show increases.

In agricultural chemicals, the fastest growing field, patenting has increased particularly in pesticides containing an organic compound as the active ingredient (e.g., Malathion). Within drugs and medicines, considerable growth has occurred in prostaglandins patenting, especially from 1980 to 1981. Expansion has also occurred in measuring and testing methods.[95]

The industries with the greatest declines in patenting tend to be electrical and mechanical. In metalworking machinery and equipment, one significant component of the decline is in metal fusion and bonding.

Several studies help to illuminate the patenting behavior of individual industries. In the drug and medical instruments industry, patent expenditures appear to be closely related to R&D expenditures and this industry seems to depend considerably on patents to protect its inventions. However, there is no such relationship in the computer industry. Firms in this industry do not appear to be using patents extensively to protect the output of their research departments, perhaps because the pace of technical change in that industry is so rapid and the lag in issuing patents so long that patents do not give these companies adequate protection for their inventions. In such cases, trade secrets may afford better protection. Alternatively, the inventions in this industry may take the form of large interconnected systems that are not very suitable for patenting.[96] The aircraft industry is also thought to have a low propensity to seek protection for its patentable inventions because of the nonexclusive licenses and rights of use that the Government automatically receives on contract-related inventions.

The propensity to seek patent protection for one's inventions in a given industry must depend in part on the effectiveness of patents in different industries in preventing the imitation of inventions by competitors. It appears that patenting does not entirely deter imitation; in one study 60 percent of the patented successful innovations in the sample were imitated within 4 years of their introduction.[97] However, patent protection increases the costs of imitation. The increase was relatively high (30 percent) in the case of ethical drugs, while it was only 10 percent or less in chemicals, electronics, and machinery. Patent protection is relatively important in the case of drugs because a new drug can be imitated on a production scale relatively easily and cheaply. However, it is harder to determine from a new electronic or machinery product how it is produced.

More generally, it is possible to estimate how much company patenting is due to the pull of the market, represented by firm sales, and how much is due to technological opportunity, represented by R&D expenditures and technology class. Over a wide range of technologies, the effect of technological opportunity seems to be the greater.[98] Since these studies do not consider patenting trends over time, they do not help directly in explaining the decline in industrial patenting in the 1970's.[99]

Table 4-4. Average annual change in patent grants to U.S. inventors, for product fields with the greatest changes: 1971–81

Product field	Percent change per year
Product fields with increases:	
Agricultural chemicals	6.1
Drugs and medicines	5.3
Paints, varnishes, and related products	.1
Product fields with largest decreases:	
Metal working machinery and equipment	−8.5
Railroad equipment	−8.1
Ordnance, except missiles	−7.4
Electrical transmission and distribution equipment	−7.2
Electrical industrial apparatus	−7.0
Ship and boat building and repairing	−6.9

See appendix table 4-13.

Science Indicators—1982

SMALL BUSINESS AND TECHNOLOGICAL PROGRESS

An important component of U.S. industry comprises companies with fewer than 500 employees. As the President has noted, the contributions of small business to innovation and employment have been particularly noteworthy. Inventors have often chosen to market their innovations through small business. Small business is ideally suited for such ventures by virtue of its greater flexibility and greater willingness to assume risks,[100] as well as its greater interest in serving relatively small markets. *Science Indicators—1976* reported on the high share of U.S. innovations due to

[94]Patenting data by product field are reported in terms of the date of patent grant. Since the year-to-year data contain considerable statistical noise, the rates of growth and decline are calculated by a smoothing process. This involves fitting a least-squares line to the logarithm of the annual patent counts and taking the antilogarithm of the resulting slope. The increase in patenting from 1979 to 1982 shown by the data in terms of application date cannot be seen in the grant date numbers because of the 2-year lag in processing applications, and because of the noise in the data by grant date.

[95]Interest in lengthening the present 17-year life of patents to compensate for regulatory delays is discussed in ref. 147, p. 80, and ref. 44, p. 74.

[96]A quantitative discussion is found in ref. 72. In addition, the high mobility of scientists and engineers in this industry and the wide availability of the results of semiconductor research militate against patenting. Some firms in this industry, of course, have earned considerable royalties from their patents, and Texas Instruments has used its patent position as leverage to gain Japanese Government permission to establish one of the few American joint ventures in Japan. See ref. 80, pp. 136-137, and ref. 71.

[97]See ref. 21. Nevertheless, there is considerable advantage in terms of marketing position in being the first to introduce a new line of products. See ref. 140.

[98]See ref. 72. R&D alone explains more of the variance in the data than do sales data alone. Also see ref. 73.

[99]For a brief treatment, see ref. 58, p. 39.

[100]See ref. 10, p. 4

small business, and its high productivity in terms of innovations per R&D dollar.[101]

Not all small companies operate in fields related to science or technology, and of those that do, not all are innovative. Still, the innovative component of small business is important enough to have received special treatment in national legislation. For example, the Economic Recovery Tax Act of 1981 contains some tax reductions of interest to small business.[102] More recent legislation has required Federal agencies to allocate 1 1/4 percent of their grants and contracts for the performance of R&D to small companies by fiscal year 1986.[103]

Much of the public policy activity with regard to small business is designed to insure the availability of sufficient amounts of venture capital to assist in the formation and expansion of new companies.[104] In 1975 the number of initial public offerings of stock in high technology small companies dropped to zero. (See figure 4-10.) While public sale of stock is only one source of small-company financing, this information serves to indicate the general lack of funds for small business at that time.

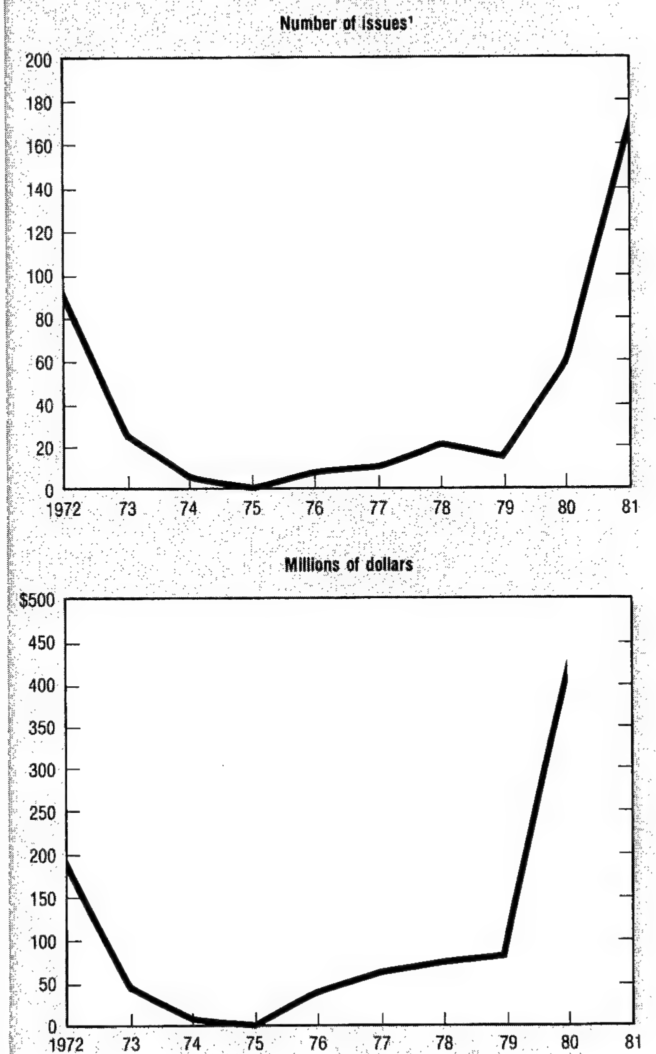
Since 1975 the situation has improved considerably. Besides the recovery from the recession of the mid-1970's, the data show the effect of simplified Securities and Exchange Commission registration requirements for small initial public offerings.[105] In addition, the capital gains tax was cut in 1978 and 1981.[106] The result is that 1981 evidently saw more high technology public offerings than any time in the preceding 10 years.

Public offerings, however, are not the only source of capital for small businesses, nor do they come in the earliest and most precarious stages in their history. While the initial sources of funding for the most part are private, the entrepreneur must soon approach the venture capital industry for money.[107]

The improved condition of this industry since 1975 is shown in appendix table 4-15. Total disbursements rose by almost a factor of 7 from 1975 to 1982. These disbursements include both high technology ventures and others.[108] The equity portion of the disbursements rose similarly. The amount of private capital committed to venture capital firms has gone up very dramatically. This table shows the pool of money available each year for new venture financings and the implementation of new technical ideas. In addition to the changes in capital gains tax rates mentioned earlier, these increases in venture fundings are due to excellent returns to investors from venture capital firms and a relaxation of Department of Labor rules in 1979 regarding pension fund investments in venture capital partnerships.

Figure 4-11 shows the venture capital industry's funding of high-technology ventures in the slack year 1975 and in

Figure 4-10
Initial public offerings of stock in high-technology companies



[1]The number of issues for 1981 is calculated on a slightly different basis from the other data. See appendix table 4-14.

Science Indicators—1982

[101]See ref. 11, p. 118. A compilation of the data conventionally used in this field is ref. 12. Also see ref. 10. The current state of U.S. research in this area is summarized in ref. 13. As these references show, small business is also considered to produce exceptional numbers of new jobs. This conclusion has been questioned (ref. 142), but more recent studies seem to support it. See ref. 165, pp. 87-88.

[102]See ref. 10, pp. 314-325.

[103]See ref. 14.

[104]For the recommendations of an earlier commission on small business, see ref. 15.

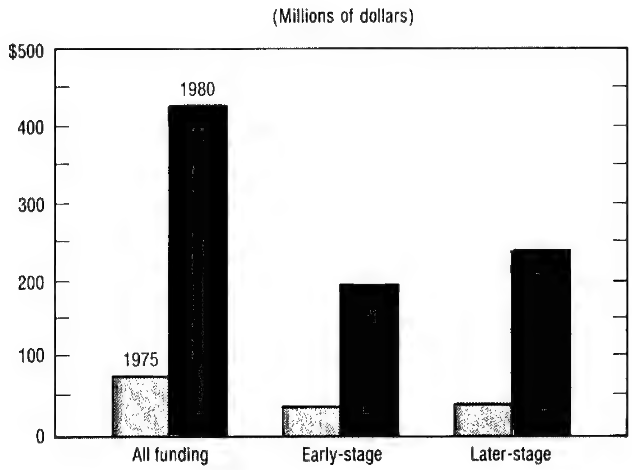
[105]See ref. 10, p. 122.

[106]*Ibid.*, p. 142.

[107]Venture capitalists provide early stage development funding as well as expansion financing for companies that have overcome initial hurdles and require additional capital for growth, but do not yet have access to public or credit-oriented institutional funding. The principal institutional source of venture capital, over and above private capital holdings, is the independent private venture capital firms. The other major source of venture capital is the group of Small Business Investment Companies (SBIC's) licensed by the Federal Government. SBIC's have access to Government loans to achieve up to a 4-to-1 leveraging of their private equity capital. Because they generally borrow a portion of their investment capital and must service the interest, they are more likely to avoid straight equity investments in early stage companies, in preference to purchasing income-producing preferred stock or debt instruments.

[108]The table excludes direct fundings of new ventures by large companies, but includes those fundings by large companies that go through venture capital companies. The discussion below will deal with high technology companies specifically.

Figure 4-11
Venture capital investments in small high-technology companies



See appendix table 4-16.

Science Indicators—1982

1980.[109] Equity financings for all new ventures came to $136 million in 1975 and $799 million in 1980; the high-technology portion was $72 million in 1975 and $425 million in 1980. (See appendix table 4-16.) The share of early stage venture funding going to all high technology fields decreased from 69 percent in 1975 to 56 percent in 1980, while the share of early and later venture capital investment remained close to 53 percent. (See appendix table 4-17.) The largest share of this funding by far goes into office, computing, and accounting machines, particularly into computer-related technology. Other tabulations show that a major share of this funding is for companies involved in producing computers themselves, but that this share dropped markedly from 1975 to 1980.[110] A large percentage increase also occurred in early stage financings in drugs and medicines. Total investments in genetic engineering companies rose from about $1 million in 1975 to about $35 million in 1980.[111]

Venture financings of high technology companies provide a measure of some of the resources available for innovation in U.S.small business. Other resource measures are found in the fact that the R&D funds spent in small companies, in constant 1972 dollars, were $1,018 million in 1980 and $971 million in 1975.[112] The resources for R&D in small business increased, but not as much as venture capital investments. However, it is widely thought that innovation in small business comes from many sources in addition to formally reported R&D.[113]

How many innovations are produced by these resources? A recent study considered the number of innovations introduced per employee from 1970 to 1979 and found that, by this measure, small business is 2.5 times as innovative as larger companies.[114] In addition, smaller companies take a shorter time to bring their innovations to market. The average time from the establishment of performance criteria to market introduction is 2 years for small firms and 3 years for larger firms. Other findings were that small firm innovations are more likely to initiate a broad line of new products and that their products are more likely to be introduced into consumer and Government markets rather than sold to companies that would use the products internally.

Foreign studies also consider the contribution of small business to innovation. A current British study finds 25 percent of significant British innovations to be due to companies with fewer than 1,000 employees, throughout the period from 1945 to 1980. This is considerably greater than these companies' share of R&D funding, but apparently less than their share of employment or net output.[115] In general, small companies in Europe do not seem to be as important to overall industrial innovation as are small companies in the United States.

Another indicator of the technological output of small business is its production of patents. A study of the rates of U.S. patenting by U.S. small business showed that the proportion of all patents to U.S. corporations that went to small companies was 19 percent in 1980.[116] The high share of patenting by small companies appears to demonstrate their technical inventiveness. On the other hand, one would

[109]The figure shows early stage financings which involve companies at the stage of proof of concept, product development, initial marketing, and initial production. Later or expansion-stage companies are those that have established production and shipping histories, yet require additional external capital to finance further plant expansion, marketing, working capital, or product development. The bars marked "all funding" show early and expansion financings together.

[110]See ref. 16, p. 28. The profitability of new ventures in the computer field has recently declined. See ref. 141. On venture financing in the semiconductor industry, see ref. 80. According to this source, shortages of capital available to small companies led to takeovers of independent semiconductor manufacturers by large U.S.and foreign concerns. Of 28 investments/acquisitions in the 1970's, 18 were by foreign interests. These developments may lead to a loss of innovativeness in the industry, as well as to a loss of U.S. control over it. By one estimate, $6.5 billion is currently invested in U.S. venture capital projects, and about 10 percent of this is foreign. See ref. 125.

[111]See ref. 16, p. 31. The growth of small-business activity in this field can be seen from the fact that in 1978 there were only 4 companies world-wide specializing in applying recombinant DNA technology to industry, with a total capitalization of $20 million. Near the close of 1981, an estimated 110 new small companies, with a total capitalization of about $70 million, were working on DNA technology. See ref. 111, pp. 11-12.

[112]See ref. 17, table B-3. These numbers apply to all R&D reporting companies with up to 1,000 employees.

[113]See ref. 19, p. 7; ref. 22; and ref. 23.

[114]See ref. 18. Ref. 157 is a recent bibliography on the contribution of small business to innovation.

[115]See ref. 19, pp. 7-8. Companies with fewer than 500 employees produced 21 percent of the innovations reported. A major study of small and medium-sized firms in Europe is ref. 123. Also see ref. 124. The available information on small business and innovation in Europe is summarized in ref. 127, pp. 53-91. Also see refs. 136 and 166.

[116]This agrees with the share of innovations due to small business found by the British study mentioned above. By comparison, less than 5 percent of industrial R&D funding is in small firms. See ref. 18, table B-3. On patenting by small companies, see also ref. 70.

expect that the R&D reported by small businesses does not represent all the innovative efforts of those companies.[117] Another possibility is that small firms patent an especially large share of their inventions, as compared with larger firms. However, a recent study failed to find evidence that smaller companies are more likely to get patent protection in connection with their innovations.[118]

Another comparison can be made of the patenting behavior of small and large companies by considering the particular product fields in which they specialize. It is evident from appendix table 4-18 that small company patenting specializes in various aspects of machinery. On the other hand, small company patenting is very slight in chemical technologies, including drugs and medicines and petroleum and natural gas.

PRODUCTIVITY

The labor productivity of a company, industry, or nation is the ratio of its produced output to the hours of labor than went into that output. Thus it measures efficiency of production.[119] Technological advance, including improved management techniques, is one of the most important factors influencing productivity improvement,[120] and technologies are frequently developed for the sake of improving productivity.

There are many problems involved in measuring productivity and in interpreting productivity data. Single indices of this kind cannot capture the complex relations among the various factors of production as they affect rates of output.[121] If productivity levels change, many influences besides changes in technology may be responsible.[122] Thus, in interpreting shifts in productivity as indicators of technology, it is advisable to focus on industries that are highly dependent on technology and to take into account those studies that show the influence of levels of capital investment and R&D spending on productivity.

Industrial productivity has attracted considerable attention as a policy problem in recent years.[123] Among the market-economy industrialized countries, the United States, while still ahead, has gradually been losing its lead in productivity.[124] From 1958 to 1965, productivity in U.S. manufacturing industry grew by an average 3.9 percent per year. The growth rate dropped to 2.8 percent from 1965 to 1973, and then to 1.4 percent from 1973 to 1981, with a notable decrease in productivity in 1974 and a slight decrease in 1980.[125]

The explanations for productivity trends in different industries are highly various and often incomplete. In aerospace, for example, productivity improvements are achieved through advanced manufacturing processes and experience in the production of each model series. Productivity improvements in 1981 were due to economies of scale because of healthy production schedules for transport aircraft. Advanced manufacturing technology has also played an important role in improving productivity. Between 1970 and 1981, the industry made great strides in advancing production machinery and know-how.

In the steel industry, most of the productivity increase from 1950 to 1980 has been attributed to technological change, with the rest due to substitution of capital for labor.[126] The semiconductor and computer industries are having difficulty in raising the vast sums that are now required for new product development and for the tools and plants needed to make and test these products.

Substantial productivity improvements in the textile industry have been due in large part to the expenditure of substantial sums on modernization and new technology, as well as to improvement of skills in managing basic human resources and assets.[127] Capital formation is named as a major problem by large metalworking companies.[128] The automobile industry is putting considerable sums into plant automation and, specifically, into robotics. This is a rapidly developing and internationally competitive area of technology in which the United States maintains a strong position. It promises to help various industries maintain the U.S. lead in productivity.[129] Since purchase or modification of capital equipment is the main vehicle through which the results of R&D lead to increases in measured productivity growth,[130] productivity growth among nations has been much better correlated with physical investment as a fraction of GNP than with R&D as a fraction of GNP.[131]

The influence of R&D expenditures on productivity is indirect, depending as it does on capital investment and other factors. It is also a long-run influence, whereas capital and labor shifts also affect R&D in the short run. However, much is already known about the influence of R&D. Private R&D capital has a relatively large effect on private-sector productivity.[132] Basic research is found to contribute significantly to productivity, although this may be a surrogate for the contribution of long-range R&D to productivity.[133] The impact per dollar of basic research is greater than that for applied research or development. R&D investments in the production of intermediate and capital goods benefit

[117]Since small business has about 30 percent of the employment of manufacturing industries and 20 percent of the sales and receipts, its production of patents is close to what would be expected, by this measure. (See ref. 24 for data.) Of course, these data include many companies that are not very technology-intensive.

[118]See ref. 21.

[119]Other definitions of productivity consider tangible capital inputs in addition to labor, and are called multifactor or total factor productivities. If all factors were considered, they would also include land, materials, energy, research, and education. See ref. 74.

[120]See ref. 75, p. 2. On the continuing effort to show the effect of "advances in knowledge" on productivity, see ref. 160.

[121]See, for example, ref. 76, pp. 6-10.

[122]See ref. 77.

[123]See, for example, ref. 89, which offers policy alternatives and discusses the role of technology.

[124]See chapter on International Science and Technology.

[125]For the entire nonfarm sector of the U.S. private business economy, productivity grew by 3.0 percent per year from 1958 to 1965, but by only 2.2 percent per year from 1965 to 1973, and 0.6 percent per year from 1973 to 1981. Data are from ref. 78.

[126]See ref. 85. On recent developments, see refs. 86 and 81. On semiconductors and computers, see refs. 82 and 94.

[127]See ref. 83.

[128]See ref. 84.

[129]See refs. 87, 88, 93, 114, and 128.

[130]See refs. 90, 95, 91, 92, and 100.

[131]See ref. 38, p. 24, and ref. 50, pp. 75-78.

[132]See ref. 161.

[133]See ref. 96.

both the producing and the purchasing industries' productivity. Specifically, R&D oriented to new processes benefits the performing industry, while R&D oriented to new or improved products, especially capital goods, benefits the purchasing industries rather than the producing industry.[134] Government-funded R&D has an indirect effect on productivity, to the extent that it stimulates private funding of industrial R&D.[135] A dollar invested in R&D may have a considerably greater effect on overall industrial productivity than a dollar invested in fixed capital.[136] This payout helps to compensate for the relatively high risk of R&D projects, which is comparable to the risk involved in oil and gas exploration.[137]

In individual industries, total factor productivity evidently is still significantly dependent on private R&D intensity, though the relationship has recently been obscured by the decline in the average growth rate of productivity.[138] Among individual firms, those performing higher levels of R&D have higher levels of growth in total factor productivity.[139] Finally, the notion of reverse technology transfer can be applied to productivity measures.[140] Companies performing R&D in foreign laboratories can improve their productivity by importing some of the technology they have developed abroad. There is some indication that such an effect occurs and can be significant.[141]

UNIVERSITY-INDUSTRY COOPERATION IN R&D

The importance of the university sector to industrial science and technology is seen in the fact that universities educate the scientists, engineers, and managers employed in industry. They also perform much of the basic research that industry develops into commercially viable products and processes. Several issues regarding the relationship between these two sectors have arisen in recent years.[142] It has been asserted that universities are no longer attuned to the needs of industries, with the result that companies have established their own graduate-type programs. Increased Federal support of universities during the 1960's altered the priorities of university research and shifted the focus of student training away from solving industry problems.[143]

Numerous arrangements have been made in recent years to increase private industry's support of academic research and thereby encourage research in areas of interest to industry. The direct sharing of research problems and results is a prominent feature of these arrangements. While each of these is negotiated individually between company and university, they fall into broad types, such as university-based institutes serving industrial needs, jointly owned or operated laboratory facilities, research consortia, industry-funded cooperative research programs under contract, innovation centers, and industrial liaison programs. Less formal arrangements include personnel exchanges, institutional consulting, unrestricted grants, and participation on advisory boards.[144] Consulting activities in particular represent an important resource that universities and colleges provide to industry.

Universities profit from these arrangements in many ways. In addition to receiving increased funds, universities do not have to comply with the accounting procedures and regulations that go with Federal support. Faculty can gain experience, offer more relevant courses, and obtain individual sponsored research projects and consulting opportunities. In some cases, sophisticated industrial experimental equipment and facilities are made available to university faculty and students. From the industry side, research results are obtained without the necessity of establishing and maintaining a large facility inhouse. In some cases, the needed talent could not be hired at all; in other cases, it would not be economical to do so; while in still others, industry laboratories would not be the right environment for the long range research efforts that are needed. Industry often sees these arrangements as a way of assisting its recruitment of new graduates.[145]

The Federal Government has sought to encourage these arrangements without committing large amounts of Federal money. Thus the Economic Recovery Tax Act of 1981 provides for a 25-percent tax credit for increases in company R&D expenses over and above base year R&D expense levels. This provision includes up to 65 percent of research contracted out to colleges, universities, and certain other research organizations. In addition, the act encourages the donation of research equipment to universities by allowing the deduction of part of the cost of such equipment as a charitable contribution.[146]

Industry Support of University R&D

Figure 4-12 illustrates the amount of support that private industry has been giving specifically to academic R&D. In terms of constant dollars, funding has gone up every year

[134] These results are summarized in ref. 97.

[135] See ref. 98.

[136] See ref. 98.

[137] See ref. 99. There is some evidence that there is little or no depreciation in the effectiveness of R&D in its subsequent influence on productivity. Continued use of the techniques produced by R&D does not diminish the influence of these techniques on productivity in subsequent years. In this way R&D differs from workers and equipment. (See ref. 97.) However, the influence of R&D on company profits does deteriorate, because of competitors' catching up with the new techniques. The obsolescence rate of R&D for this purpose is about 20 to 30 percent per year, with perhaps 80 percent of all profits being realized in 5 years. Another study finds the returns increasing for the first 4-6 years after the R&D investment, and then decreasing. See ref. 135. This study found an upward trend in the profitability of R&D in the late 1970's.

[138] See ref. 101. Earlier results did suggest some decline in the effectiveness of R&D. See ref. 103. Another study, showing generally significant contributions of R&D to the productivity of individual industries, is ref. 159.

[139] See ref. 102.

[140] See the discussion of reverse technology transfer earlier in this chapter.

[141] See ref. 68.

[142] See ref. 105, pp. 151-152.

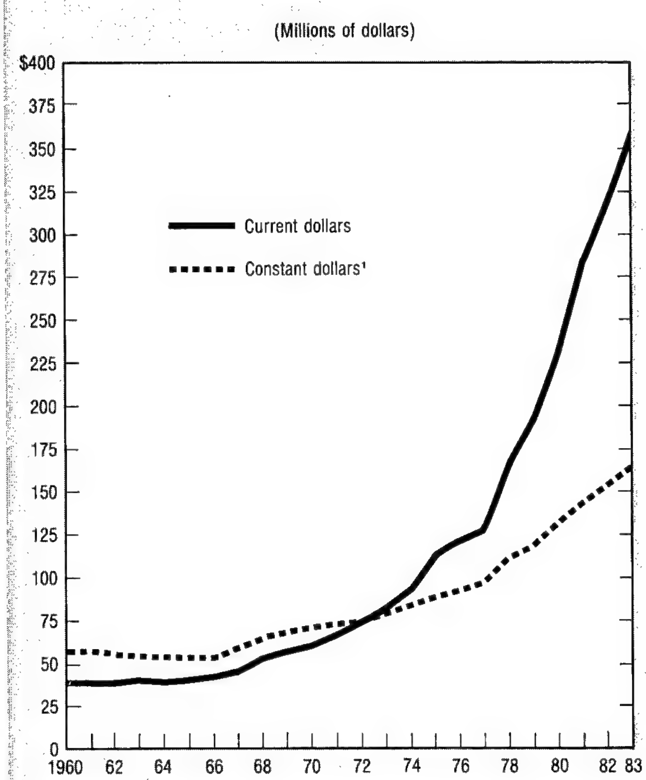
[143] See the section of this chapter on S/T Personnel in Industry. For the problems of the academic sector in general and its sources of funding, see the chapter on Academic Science and Engineering.

[144] For a full discussion of these arrangements, and in general of university-industry relations in science and technology, see ref. 111.

[145] The reasons for increased university-industry cooperation, as well as the obstacles to it, are discussed in ref. 109. Also see refs. 133 and 162.

[146] See refs. 37, 36, and 110.

Figure 4-12
Industry's expenditures for R&D in colleges and universities



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
Note: Preliminary data are shown for 1981 and estimates for 1982 and 1983.
See appendix table 4-19.

Science Indicators—1982

since 1970, increasing by 11 percent from 1980 to 1981 alone, and having doubled since 1970. About half of R&D support is in engineering.[147] For example, in 1980, 23 percent of extramural research funds for chemical engineering departments came from industry. In 1981, aerospace companies provided universities with about $28 million for R&D. Over 80 percent of this went to engineering and applied science programs.[148]

Figure 4-12 excludes many mechanisms of R&D support, such as unrestricted grants that the university chooses to spend on research, as well as R&D funds from nonprofit foundations that pass along funds received from industry. It also excludes cooperative research arrangements of all kinds. According to a recent estimate, industry invested through all mechanisms a total of $500 million in R&D at universities and colleges in fiscal year 1981.[149] This was about 1.5 percent of the R&D funding that industry spent internally. It is made up of a projected $288 million in grants and contracts, $96 million in gifts earmarked for research, and $116 million in consulting fees to faculty members.[150]

In addition, there has been a proliferation of cooperative research agreements, particularly in biotechnology. The biotechnology agreements announced in 1981 have a total annual dollar value of about $8.5 million.[151] Plans are being made for additional cooperative arrangements, but it is not yet clear how many will come to fruition, or how many represent genuinely new R&D rather than the consolidation of present efforts.

Information Transfer Between Industry and Academia

The knowledge transferred between the industrial and academic sectors is an essential component in the advancement of the Nation's science and technology enterprise. In its basic research effort, academia provides much of the foundation on which industry can build to remain competitive throughout world markets. Although a more thorough examination of this topic is provided elsewhere,[152] some indicators of these intersectoral flows are presented below.

One indicator of the transfer of information between industry and academia is the number of scientists and engineers in industry who report teaching as their secondary work activity. In 1981, some 3,300 doctoral S/E's in industry (3 percent of all industrial S/E doctorate holders) reported teaching as their secondary responsibility. This may be an upper bound since some of these personnel may be involved in in-house training.

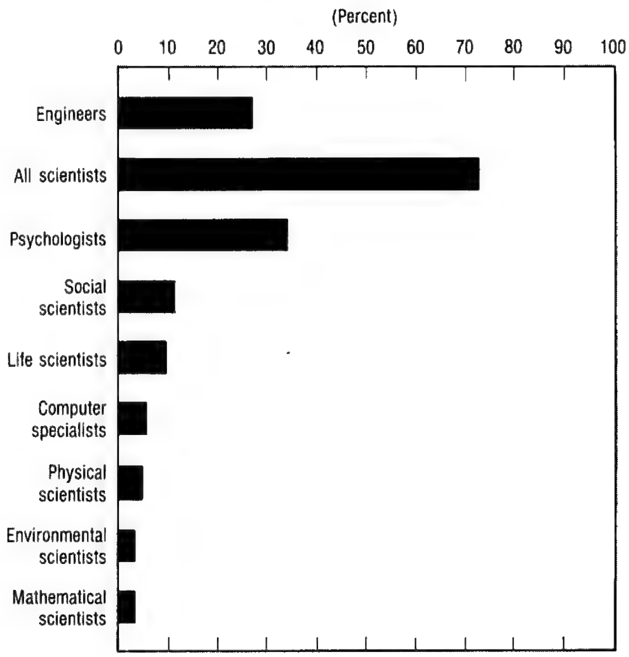
Many more doctoral scientists than doctoral engineers in industry reported teaching as a secondary work activity. In 1981, almost three out of four doctoral S/E's reporting teaching as a secondary responsibility were scientists. (See figure 4-13.) Almost half (47 percent) of these scientists were psychologists. Social scientists (16 percent of scientists reporting teaching) were the next most likely to be involved secondarily in teaching. In contrast, very few of the doctoral scientists in industry reporting teaching as secondary work were mathematical (5 percent of teaching scientists) or environmental scientists (5 percent of teaching scientists).

The flow of personnel between industry and academia is also an indicator of the degree of information transfer. Between 1979 and 1981, about 3 percent of the employed holders of doctorates shifted between the academic and industrial sectors. (See figure 4-14.) Over four-fifths of this shift was from academia into industry. About 4,600 doctoral S/E's moved into industry from universities and colleges whereas only about 1,000 left the industrial sector for academia. There was little difference in this mobility rate between doctoral scientists and engineers.

When research is planned and conducted jointly by industry and university researchers, it becomes the focus of much of the information transfer described above. An indication of the extent of this cooperation can be found in trends in the number of leading research journal articles having both industry and academic authors. This number

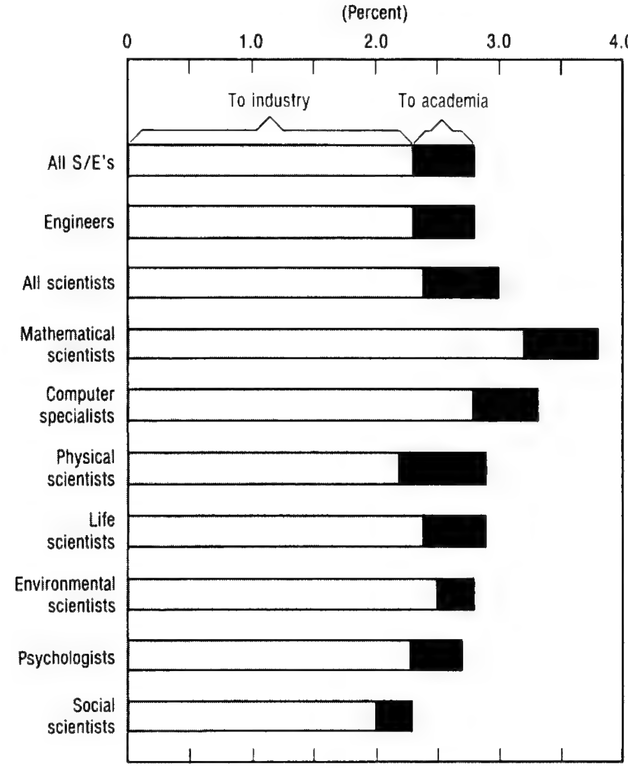
[147]See ref. 111, p. 22. This estimate is for 1979.
[148]See ref. 162, p. 6.
[149]See ref. 134.
[150]By another estimate, the total corporate contribution to university R&D was $400 to $450 million in 1980-81. See ref. 111, p. 77.
[151]See ref. 134.
[152]See chapter on Academic Science and Engineering.

Figure 4-13
Distribution by field of doctoral scientists and engineers in industry reporting teaching as a secondary work activity: 1981



See appendix table 4-20. Science Indicators—1982

Figure 4-14
Flow[1] of doctoral scientists and engineers between industry and academia: 1979 to 1981



[1]Percent of total 1979 academic and industrial employment that moved from one sector to the other by 1981.
See appendix table 4-21. Science Indicators—1982

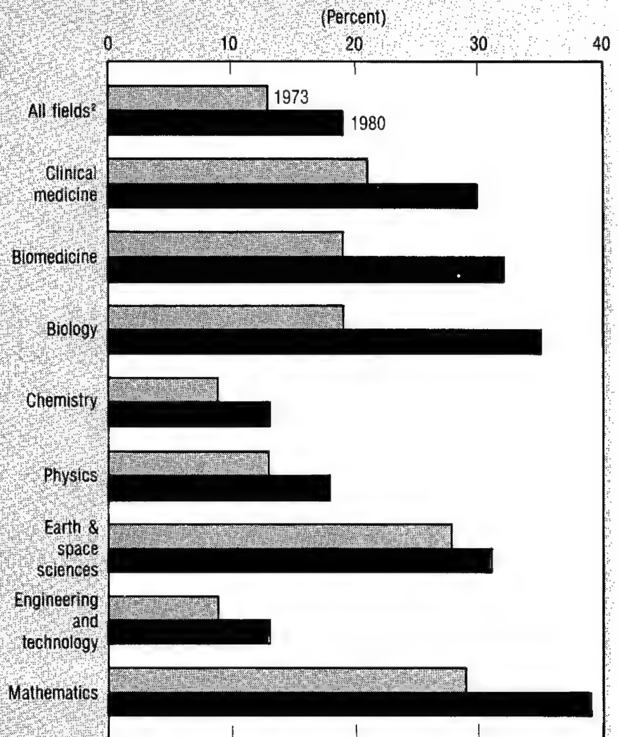
has risen 29 percent over the 1973-80 period for eight major fields even though the number of all articles with industry authorship dropped 14 percent. (See appendix table 4-22.) In all eight fields, except engineering,[153] the number of these jointly authored industry/university articles rose considerably, with the greatest increases in physics (72 percent), biomedicine (50 percent), and clinical medicine (42 percent). Moreover, industry authors publish jointly with university authors much more often than with authors in the Government or in another industrial company. Figure 4-15 shows that, by a measure of relative cooperation, research in some fields is much more cooperative than others, and that the greatest increases have occurred in the fields of biomedicine, biology, and mathematics. In the higher and more rapidly growing areas of cooperative research, there is a strengthening of the research relationship between industry and universities. In all eight fields, cooperation has been growing. Industry cooperation with all sectors, including academia, rose over the 1973-80 period, about 36 percent when measured by cooperative authorship of research articles. Thus, although most of the rise is accounted for by academic research cooperation, some also occurred with other U.S. sectors and with researchers from other countries.

A traditional form of showing dependence of research on previous research is the use of citations to prior published work. By comparing relative citation ratios[154] from each of these sectors toward the other, the direction and relative level of information transfer can be determined for each field. (See table 4-5.) For example, in 1978-80, industry drew more heavily on 1978 university research articles than university research acknowledged industry-based prior research. This net preference for 1978 university research was found for all fields except physics, where industry research is apparently more influential. The tendency of industry researchers to acknowledge university-based rather than industry-based work persisted for research published during 1973-78 in the fields of clinical medicine, chemistry, earth and space sciences, and engineering. Thus, the antecedents of much industry research are provided by universities, while the significance of industrial physics research to its university counterpart is very clear.

[153]Engineering articles dropped only 1 percent (4 articles fewer in 1980 than in 1973).

[154]A citation ratio of 1.00 would mean that the cited sector received a share of citations in that field equal to its share of publications in that field. Because all sectors tend to cite their own research more than others', these ratios all are less than unity. However, their relative magnitudes can be compared.

Figure 4-15
Portion of all journal publications[1] written with industry participation that are co-authored with universities



[1]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.
[2]See appendix table 1-13 for a description of the subfields included in these fields.
See appendix table 4-22. Science Indicators—1982

Table 4-5. Relative citation ratios[1] between industry and university articles[2] published in 1973 and 1978.

Field[3]	1973	1978
	Citations from universities to industry	
All fields	.38	.37
Clinical medicine	.56	.41
Biomedicine	.64	.56
Biology	.55	.54
Chemistry	.39	.38
Physics	.71	.87
Earth and space sciences	.53	.42
Engineering and technology	.46	.43
Mathematics	.77	.69
	Citations from industry to universities	
All fields	.57	.52
Clinical medicine	.72	.76
Biomedicine	.73	.70
Biology	.80	.61
Chemistry	.58	.60
Physics	.47	.43
Earth and space sciences	.76	.80
Engineering and technology	.58	.53
Mathematics	.69	.77

[1] A citation ratio of 1.00 would mean that the cited sector received a share of citations in that field equal to its share of publications in that field. Because all sectors tend to cite their own research more than others', these ratios are all less than 1.00. However, their relative magnitudes can be compared.

[2] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[3] See appendix table 1-13 for a description of the subfields included in these fields.

See appendix table 4-23.

Science Indicators—1982

OVERVIEW

Private industry is the sector of the U.S. economy in which the scientific and technological developments of all sectors are employed in the production of economically important innovations. The health of industry's efforts at technological innovation depends on the training and skills of the scientists and engineers (S/E's) employed in industry. From 1976 to 1981, the number of S/E's in industry rose by 47 percent, largely because of the increased employment of computer specialists. A notable increase has occurred in the number of new employees holding master's and doctoral degrees. From 1976 to 1981, the work activity that experienced the largest growth was production and related activities, including inspection.

Manufacturing industries employ 60 percent of the engineers in private industry and 40 percent of the scientists. While total employment in manufacturing increased only 3 percent from 1977 to 1980, S/E employment increased 20 percent. The ability of high technology industries to remain at the technological forefront, and the ability of older industries to take advantage of possible technological improvements, depends on the availability of sufficient numbers of new S/E graduates. In late 1981, management personnel in industry reported shortages of S/E personnel in many fields. However, by the late summer of 1982, respondents reported that it had become easier to hire "new entrant" scientists and engineers. The change is attributed to general market conditions, rather than to changes in specific industries or an increase in the supply of new graduates.

Expenditures for R&D serve as one indicator of the level of innovative effort in U.S. industry. In 1981, total expenditures in industry were about $52 billion, or 72 percent of all R&D expenditures in the United States. From 1979 to 1981, the rate of increase in constant dollars was 6.5 percent per year. This increase has been sustained mainly by private sources of funding. Since 1967, industry itself has supported over half of industrial R&D. This support increased by 7 percent per year in constant dollars from 1977 to 1981. This high rate of increase, however, may not continue for reasons including economic uncertainty and changes in the price of labor and capital. Recent tax and regulatory policies are intended to improve the situation.

Unlike private funding, Government funding to industry is below its peak level in constant dollars, which was reached in 1966. However, Government support did increase from 1975 to 1981 at a rate of 3.5 percent per year. Half of Federal R&D support goes to the aircraft and missiles industry, and another one-fourth goes into the electrical equipment industry. Large increases in defense spending are in progress, with the result that Government funding

for industrial R&D is expected to increase more rapidly than private funding for the first time in many years.

In a few industries, such as aircraft and electrical equipment, increases in Government defense spending will directly add to R&D expenditures. Other industries are less dependent on Government funding, and when increases occur, they are more likely to be the response of private industry to increased competition. This is true in computers and in professional and scientific instruments. In both cases, the competition is principally Japanese. R&D increases in consumer goods industries are often due to domestic competition. Japanese competition is serious in the electronic components industry, where considerable assistance is also expected from DOD. The motor vehicles and equipment industry feels this kind of competition, but in this case the loss of sales seems to be so great that funds are not available for needed technical improvements.[155] This industry is also heavily affected by Government regulation in the form of pollution, safety, and fuel economy standards. Regulation has affected the drug industry in the form of FDA approval requirements. Efforts are being made to reduce this burden.

The drug industry has reached a high level of international integration, in that the U.S. multinational drug companies perform considerable R&D abroad and introduce to the United States many innovations that they create overseas. In 1981, all chemical companies together spent 13 percent as much on R&D abroad as on R&D in the United States, while the drug industry spent much more. For all industry, 9 percent as much was spent abroad as in the United States. Other industries with high levels of overseas R&D are motor vehicles and other transportation equipment (17 percent in 1974) and petroleum (11 percent in 1981).

The technology transferred back to the United States as a result of these expenditures has increased markedly since the mid-1960's. In 1979, for example, about half of the R&D funds that the chemical industry (including drugs) spent abroad led to such technology transfer. The level was even higher (80 or 90 percent) in the case of machinery and scientific instruments. Most of these technologies took the form of new products.

The rate at which U.S. corporations take out American patents can serve as an indicator of the rate at which they are producing technical inventions. These inventions provide a pool from which subsequent innovations may be developed. American inventors filed the greatest number of successful U.S. patent applications in 1969. From 1969 to 1979, patenting by American inventors dropped at an average rate of 1.7 percent per year, but from 1979 to 1982 it increased again by an estimated 1.7 percent per year. Most of this movement is due to those inventors employed by private corporations; they receive 70 percent of all U.S. patents to U.S. inventors. Thus, U.S. industry has been producing fewer patented technical inventions.

A few product fields have resisted the trend and have actually experienced increased patenting. For example, agricultural chemicals saw a 6.1 percent annual rate of increase in patent grants from 1971 to 1981. Much of this activity was in new pesticides. Similarly, drugs and medicines saw a 5.3 percent rate of increase. On the other hand, there were particularly large patenting decreases in some mechanical and electrical technologies.

Small business in the United States is often exceptionally innovative because of its flexibility, willingness to take risks, and ability to serve small markets. The importance of small business to industrial technology has been recognized in recent legislation. One of the principal needs of small business is venture financing. New issues of stock in high technology companies increased from zero in 1975 to about 170 in 1981. This increase was due to many developments, including the end of the mid-1970's recession and two decreases in the capital gains tax. Venture capital companies provide funding at an earlier stage in the history of a new small company. Equity financings from these sources increased from $136 million in 1975 to $799 million in 1980. Slightly more than half of this money went to companies in high technology fields. By far the largest share of high technology venture capital goes into computer-related technology. There has been a considerable increase in the share going to communication equipment, electronic components, and biotechnology. A large percentage increase occurred in initial financings in drugs and medicines. Total investments in genetic engineering companies rose from about $1 million in 1975 to about $35 million in 1980.

By recent estimates, small companies produce 2.5 times as many innovations per employee on average as large companies and take a shorter time to bring their innovations to market. In terms of inventions, small business gets about 20 percent of the patents granted to U.S. industry. By comparison, small business has less than 5 percent of industry's R&D funding. Small companies specialize in patenting in mechanical technologies, where there have also been large decreases in the number of patents they receive. For the most part, these are not high technology fields.

Only a few indicators exist that help to show changes in the state of American industrial technology. One such indicator is labor productivity. This indicator applies only to process technology, including capital equipment, and reflects also all the nontechnological influences on process efficiency. While productivity in U.S. manufacturing industry grew by an average 3.9 percent per year from 1958 to 1965, the annual rate of growth dropped to 2.8 percent from 1965 to 1973, and to 1.4 percent from 1973 to 1981, with a few years of negative growth. As a result, the U.S. lead in productivity over other industrialized market-economy countries is diminishing. Individual industries often experience difficulty in improving their productivity because of capital shortages that make it difficult to purchase equipment embodying the latest technology. Other problems include anti-pollution regulations and shortages of trained scientists and engineers. In spite of recent declines in productivity growth, R&D expenditures are still seen as having a positive impact on productivity.

Cooperation between the industry and university sectors in R&D is beneficial to both and is on the increase. Industrial technology draws heavily on the R&D base provided by the universities. Direct R&D grants and contracts to universities doubled in constant dollars from 1970 to 1980 and increased by 11 percent from 1980 to 1981. Most of this funding was for basic research. Joint publication of

[155] See ref. 46, pp. 242-253.

journal articles by university and industry authors increased 29 percent from 1973 to 1980, even though industry's total output of articles decreased.

The overall picture of industrial science and technology emerging from these indicators is mixed. On the side of resources, many positive things are happening. Private R&D funding has been increasing for several years, and Government funding is now increasing in the defense area. Some tax and regulatory burdens are being lifted. Venture financing for high technology small business has never been higher. Corporate support for R&D in universities, though still relatively small, is increasing, with many new cooperative arrangements being devised. However, only a little of the benefit from these measures can yet be seen. For example, corporate patenting dropped notably from 1969 to 1979, though it seems to have turned up since then. Thus, the indications are that the improvement of American industrial technology, with its social and economic benefits, will be a long-term process and will require constant monitoring.

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Chapter 5
Academic Science and Engineering

Academic Science and Engineering

HIGHLIGHTS

- Our Nation's colleges and universities play an important role in determining the nature and quality of science and technology in the United States. They do so by serving as the home for independent scientific inquiry and experimentation and as the primary training site for future scientists and engineers. No less important is the contribution these institutions make to the scientific and technological literacy of all students.

- Between 1981 and 1983, national support for academic research and development declined by 3 percent in constant-dollar terms after reaching historically high levels in 1981. The 12-percent average annual constant-dollar growth rate for academic R&D observed in the 1960's slowed to 2.8 percent in the 1970's, and is estimated to have remained essentially constant since 1980. (See p. 125.)

- Between 1972 and 1981, a significant shift was reported in the relative emphasis on basic research and on applied research and development by our Nation's colleges and universities. Academic expenditures for applied research and development (which are almost all in the applied research area) were estimated to have grown in constant-dollar terms at an average annual rate of 7.6 percent, six times the rate for basic research support. Basic research has thus declined as a proportion of academic R&D expenditures from a level of three-fourths in 1972 to little over two-thirds of the total in 1981. (See pp. 127-128.)

- Between 1973 and 1981, the number of doctoral S/E's employed at academic institutions grew at an average annual rate of 4.5 percent, one percentage point below the overall growth rate for all doctoral S/E's. The lower rate of growth in academic employment was offset by industrial S/E employment which increased at an average annual rate of 8 percent during this period. (See p. 123.)

- Slower growth in the number of faculty since 1968 has produced a decline in the representation of young faculty in S/E departments. The proportion of recent doctorates in full-time faculty positions in doctorate-granting institutions declined sharply from 39 percent in 1968 to 28 percent in 1974 to 21 percent in 1980. (See pp. 124-125.)

- The number of full-time-equivalent academic R&D scientists and engineers increased at an average annual rate of 4 percent between 1973 and 1978, but only by 1 percent per year between 1978 and 1981. The recent lower growth rate is consistent with slower growth rates for academic constant-dollar R&D funding. (See p. 131.)

- Foreign students represented more than 20 percent of all full-time students enrolled in graduate S/E programs in 1981. Between 1974 and 1981, foreign students accounted for nearly 50 percent of the net growth in full-time graduate S/E enrollment. In 1981, 43 percent of all full-time graduate engineering students enrolled in doctorate-granting institutions were foreign citizens. Foreign students also represented a sizable proportion of full-time graduate enrollments in the mathematical and computer sciences (36 percent) and the physical sciences (27 percent). (See pp. 121-122).

- Some measure of understanding of science and technology is an essential component of a broad-based undergraduate education in the modern world. U.S. students completed college in 1980, however, with less course work in science required of them than was required of graduates in 1967. On average, students graduating in 1980 met the natural sciences requirement by completing 9 credit hours of study in the sciences out of a total of 125 credit hours required for graduation—down from the average 12 credit hours of science study required in 1967. (See pp. 126-127.)

- There is concern that academic scientists and engineers should have at their disposal the up-to-date scientific equipment important to assure the continued advancement of science and technology. Universities and colleges, for example, spent approximately $420 million for separately budgeted research equipment in 1981—an estimated 6 percent of all separately budgeted R&D expenditures. More than two-thirds of this amount was provided by the Federal Government. A preliminary study of selected fields in 38 leading academic R&D institutions revealed that almost 50 percent of the instruments in the laboratories surveyed were less than 5 years old, while more than 25 percent of the instruments were more than 10 years old. (See pp. 132-133.)

- Academic institutions provide about two-thirds of the research literature in the most influential science and technology journals, a ratio that has increased slightly over the past 10 years. The 10 academic institutions publishing the most research articles typically account for more than one-fifth of these academic-based publications. There is evidence of considerable growth in cooperative research being conducted between U.S. research institutions. Coauthored articles with at least one writer employed in a U.S. university or college increased from 39 percent in 1973 percent in 1973 to 48 percent in 1980. In four of the eight major fields examined, U.S. academic authors most frequently coauthored with researchers employed by the Federal Government. (See pp. 135-138).

- The additions of new research results to the body of knowledge found in university libraries may not be expanding as fast as it has in the past. For example, the number of new volumes added each year to 75 of our Nation's largest research libraries declined by 23 percent between 1970 and 1980, while constant-dollar expenditures for all types of library materials remained at nearly the same level. However, the 30 largest research libraries continued adding new volumes at a growing rate between 1976 and 1980, although there continues to be a decline in the proportion of their collections representing new acquisitions. (See pp. 133-134).

Our Nation's colleges and universities play an important role in determining the nature and quality of science and technology (S/T) in the United States. They do so by serving as the home for independent inquiry and scientific research and as the primary training site for future scientists and engineers. No less important, however, is the contribution these institutions make to the general education of all students in the theories and methods of science and technology.

The success of academic science and engineering in fulfilling its dual research and teaching mission depends on several factors, including: a supportive institutional environment in which the activities of science and engineering (S/E) can be carried out; dedicated and talented faculty; adequate resources for research and teaching; and bright, motivated students.

There are a number of significant issues in higher education that have important implications for the future of academic science and engineering, for example, the escalating costs of operating and maintaining facilities, and the effects of government regulation on the administration of academic research activities.[1] Furthermore, the anticipated decline in enrollments in the 1980's after almost two decades of unprecedented growth will have profound effects in its own right and will mean that the existence of a substantial number of tenured faculty hired during the recent growth period may prevent for some time the entrance of new graduates into faculty positions.[2]

Clearly, the future of academic science and engineering is intimately bound to the future of higher education in this country. Many of the indicators selected for presentation in this chapter, therefore, describe trends in academic science and engineering against the broader backdrop of higher education. The first section describes the basic characteristics of the academic science and engineering system, including trends in the number of institutions that offer S/E programs, the students enrolled, and the degrees awarded.

The second part of the chapter examines recent changes in the availability of resources for academic science and engineering activities. These include public and private support for research and development, up-to-date scientific instruments, adequate research libraries, and support for graduate training in the sciences and in engineering.

Just as higher education is at the service of the public, academic science and engineering serve society in many ways. In addition to producing skilled scientists and engineers (S/E's), our universities and colleges are expected to increase the scientific and technical knowledge base. Indicators have thus been included in the final section of the chapter describing recent trends in the publication of scientific information and the patenting of ideas and inventions by university and college faculty.

MAGNITUDE AND CHARACTERISTICS OF THE SYSTEM

The 1980's will in all likelihood be watershed years for American higher education. The expansion that has occurred since World War II in the number and size of institutions will slow because of demographic, economic, and other factors. Indeed, an overall contraction in the higher education system has been projected as the number of college age individuals declines in the middle of this decade and into the 1990's.[3]

The prominent role accorded science and technology in U.S. and world affairs has meant that the academic science and engineering enterprise has experienced somewhat different patterns of growth and development than has higher education as a whole. The disproportionate growth in science and engineering enrollments in the 1960's, for example, was heavily influenced not only by burgeoning job opportunities, but also by Federal interest in science and technology and by public perception that careers in S/E were valuable to society's goals.[4] It is unclear to what extent science and engineering will be affected by the anticipated changes in the higher education system predicted by some analysts. However, the data that follow suggest that signs of some important changes in existing patterns of enrollment and support for academic science and engineering have already appeared.

Institutions for Science and Engineering Education

A little over 100 years ago, fewer than 2 out of every 100 Americans between the ages of 18 and 21 enrolled in higher education.[5] Today, about 3 out of 10 individuals of

[1]See ref. 1, pp. 8-10 and ref 89.

[2]The labor market consequences of declining enrollments in higher education have been the subject of numerous studies. Among the more recent are refs. 2, 3, 4, 5, and 100.

[3]Numerous studies have addressed possible management and administrative strategies for higher education institutions in the 1980's, although assumptions about enrollment levels differ widely. Some examples include refs. 2, 6, 7, and 8.

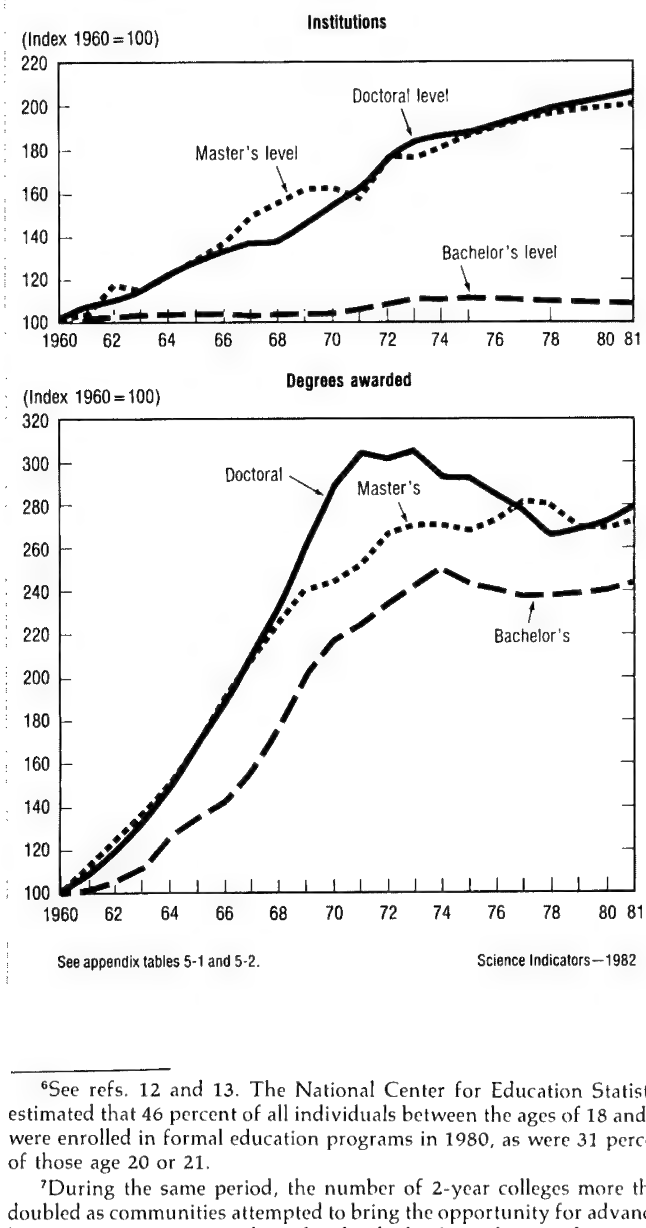
[4]Numerous public opinion polls during that time revealed the high value placed on professional employment in the sciences. See, for example, ref. 9, and related discussions in ref. 10 and chapter 3, Science and Engineering Personnel, regarding factors that influence student choice of science as a career. See also chapter 6 on public attitudes.

[5]See ref. 11.

college age are enrolled in postsecondary programs offered by about 3,000 educational institutions across the country.[6]

The 1960's will be remembered for the demand placed on our educational institutions by the rapid expansion of the college age population. As the postwar baby boom generation became eligible for and sought higher education in greater numbers than ever before, the education community responded by establishing new postsecondary institutions or by expanding existing colleges and universities to meet the demand. By 1981, the number of 4-year postsecondary institutions had grown by more than one-third from 1960 levels. (See appendix table 5-1.)[7]

Figure 5-1
Relative growth in the number of institutions offering S/E degrees and the number of S/E degrees awarded



See appendix tables 5-1 and 5-2.

Science Indicators—1982

Of the 1,447 4-year institutions offering science and engineering degrees in 1981, 54 percent were baccalaureate institutions, 25 percent offered both master's and baccalaureate degrees, and the remainder—about 20 percent—offered doctoral degrees as well as baccalaureate and master's degrees.

As figure 5-1 reveals, the number of baccalaureate institutions offering S/E degrees has grown very little since 1960, compared to the number offering advanced degrees—which virtually doubled during that time.

While the number of institutions offering advanced science and engineering degrees has doubled since 1960, the number of S/E master's and doctoral degrees awarded each year has nearly tripled. (See figure 5-1.) By 1981, the number of science and engineering doctoral degrees awarded in that year alone reached 17,000, up from a total of 6,000 in 1960. The number of master's degrees more than doubled from 1960 levels to a total of about 55,000 in 1981. The number of S/E baccalaureate degrees awarded annually rose over 200 percent to a total of nearly 295,000 in 1981.

The growth in doctorate- and master's-granting institutions parallels the increased production of advanced degrees in science and engineering, although the latter expanded at a faster rate. There is virtually no relationship, however, between the growth in the number of baccalaureate degrees awarded and changes in the number of undergraduate institutions between 1960 and 1981. This is due to the fact that more than 80 percent of bachelor's degrees are awarded by colleges and universities with advanced science and engineering degree programs.[8]

In recent years, the growth in the number of 4-year institutions offering degrees in science and engineering has slowed, growing at an average annual rate of 0.4 percent between 1973 and 1981 in contrast to an average annual growth rate of 2.2 percent between 1960 and 1973. The number of institutions offering S/E degrees will probably remain at current levels, or possibly decline, in the coming years.

Trends in Earned Degrees

The recent history of science and engineering baccalaureate production shows sharp growth in the 1960's and early 1970's, followed by a decline during the mid-1970's, and subsequent stabilization in output between 1976 and 1981.[9] Thus, the 1981 output of 295,000 science and engineering baccalaureate degrees matches the degree production for 1975; this level is, however, about 3 percent lower than the alltime high of 305,000 degrees awarded in 1974. At the master's degree level, the output of over 57,000 science and engineering degrees awarded during the 1977 academic year declined to about 54,000 in 1980, a level comparable to the output throughout the 1973-76 period. In 1981 S/E master's degree production totaled about 55,000. The number of doctoral S/E degrees awarded decreased about 10 percent from 19,000 during the 1971-73

[6]See refs. 12 and 13. The National Center for Education Statistics estimated that 46 percent of all individuals between the ages of 18 and 19 were enrolled in formal education programs in 1980, as were 31 percent of those age 20 or 21.

[7]During the same period, the number of 2-year colleges more than doubled as communities attempted to bring the opportunity for advanced learning to a greater number of individuals. See ref. 12 and appendix table 5-1.

[8]In general, doctoral institutions awarded 54 percent of all baccalaureate degrees conferred in the United States in 1980, master's-granting institutions awarded 27 percent, and baccalaureate-granting institutions awarded 19 percent. See ref. 26.

[9]See also chapter 3, Science and Engineering Personnel, for a discussion of the relation of baccalaureate degree trends to the production of doctoral scientists and engineers.

peak period to little more than 17,000 in 1977 and has remained at that level. Thus, the most recent data depict a lower but stable output in S/E degree production at both undergraduate and graduate levels compared to degree production earlier in the decade.[10]

The ratio of science and engineering degrees to total degrees has also shown a general decrease. At the baccalaureate level, S/E degrees awarded in 1981 accounted for 29 percent of the total baccalaureate production; this level has remained stable for the past 4 years, but is down from 32 percent in 1970. Similarly, the proportion of S/E degrees at the master's level went from 24 percent to 18 percent during the 1970-81 period. At the doctorate level, the proportion of S/E degrees awarded has declined from 64 percent in the mid-1960's to 55 percent in 1981, a decrease of 9 percentage points. The science and engineering share of doctorates has remained essentially at 55 percent since 1974.

Although the number of science and engineering baccalaureates awarded annually has declined since 1974, trends have varied among S/E fields. (See figure 5-2.) The most significant gains at this level have occurred in the computer sciences and engineering. Between 1970 and 1981, for example, the number of bachelors degrees awarded annually in the computer sciences increased tenfold (from 1,500 to 15,000). The number of engineering degrees awarded, which declined from about 47,000 in 1973 to about 39,000 in 1976, has increased at an average annual rate of about 10 percent since then, exceeding 64,000 in 1981. This is one sign that students enrolling in college are responding to market forces, entering fields where job opportunities are best.

An increase in the number of computer science degrees awarded annually has also occurred at the doctorate level. However, the sharp growth rate in engineering degrees at the baccalaureate level since 1976 has not been evident among doctorate recipients. This may be due to the favorable employment opportunities recently available to undergraduate degree holders, providing a disincentive to further graduate study. A steady decline occurred in the number of doctorates awarded in engineering as well as the physical sciences between 1974 and 1981. However, the first actual increase in engineering doctorate production occurred in 1982, a trend which may persist for several years based on continuing, significant increases in the number of engineering baccalaureate and master's degrees awarded.

Foreign Participation in U.S. Higher Education

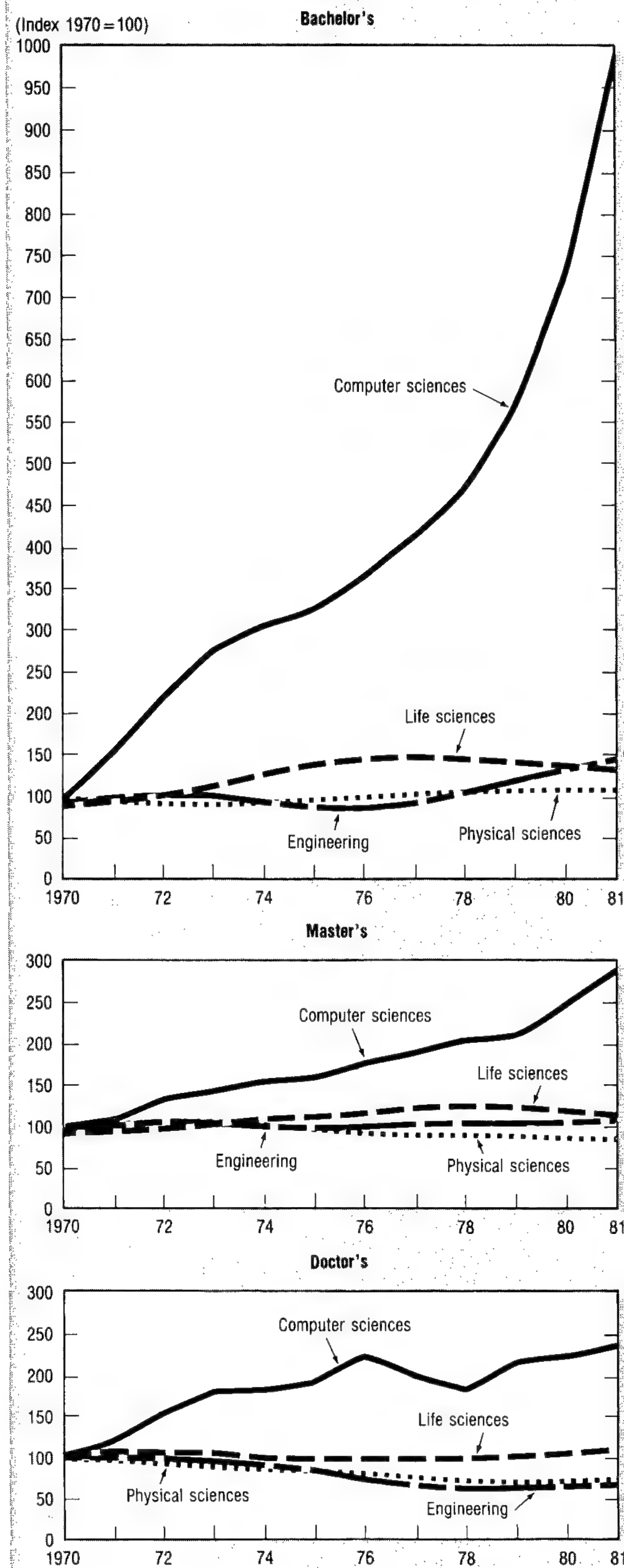
While the number of Americans enrolled in graduate programs in all fields has increased only slightly in recent years, the number of foreign students enrolled in U.S. doctorate-granting institutions has grown dramatically.[11] By 1981, foreign students represented more than 20 percent of all full-time students enrolled in graduate S/E programs in doctorate-granting institutions, or nearly 53,000 individuals.[12] Although foreign students represented only

[10]See ref. 15.

[11]See ref. 16, pp. 27-28. See chapter 1 for a fuller discussion of the role academic exchange plays in international science and technology.

[12]See ref. 19. The Institute of International Education estimated that one-third of foreign students enrolled in graduate degree programs in U.S. educational institutions in 1981/82 were from Taiwan, Iran, and India. See ref. 20 and appendix table 5-3.

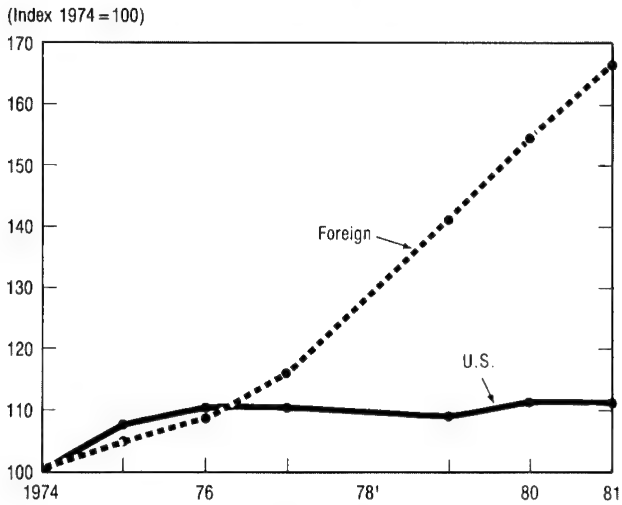
Figure 5-2
Relative growth of science and engineering degrees by level and selected fields



SOURCE: National Science Foundation, *Science and Engineering Degrees* (NSF 82-307), pp. 35, 40, 50, and 51, and unpublished data.

Science Indicators—1982

Figure 5-3
Relative growth of full-time graduate science and engineering enrollment in doctorate-granting institutions by citizenship



'Data were not collected by citizenship in 1978.
SOURCE: National Science Foundation, *Academic Science/Engineering, Graduate Enrollment and Support, Fall, 1981* (NSF 83-305).

Science Indicators — 1982

Table 5-1. Foreign students as a percent a full-time science and engineering graduate enrollments in doctorate-granting institutions: 1974 and 1981

Field	Percent 1974	1981
All S/E fields	16	23
Engineering	33	43
Physical sciences	21	27
Environmental sciences	10	14
Mathematics & computer sciences	19	36
Life sciences	12	13
Psychology	3	4
Social sciences	13	20

SOURCE: National Science Foundation, *Academic Science/Engineering, Graduate Enrollment and Support, Fall 1981* (NSF 83-305).

one-fifth of the full-time science and engineering graduate enrollments in 1981, they accounted for nearly 50 percent of the net growth in students enrolled in graduate S/E programs between 1974 and 1981. (See figure 5-3.) As a proportion of full-time graduate enrollments in doctorate-granting institutions, foreign student enrollments expanded in every S/E field between 1974 and 1981. (See table 5-1.)

Among doctoral fields, engineering reports the largest proportion of full-time foreign graduate students—43 percent of the total number of full-time engineering graduate students in 1981.[13] The next largest fields are the mathematical and computer sciences with 36 percent of all full-time graduate students being foreigners, the physical sciences with 27 percent (equally distributed between chemistry and physics), and the social sciences with 20 percent (chiefly in economics and political science). Data on new Ph.D.'s reveal that nearly 80 percent of the total number of non-U.S. citizens receiving S/E doctoral degrees in 1982 held temporary visas. This proportion varied from a high of 92 percent in agriculture/forestry to a low of 58 percent in psychology.[14]

Another area in which foreign scientists and engineers have come to represent an increasing proportion of total participants is postdoctoral research training. While the number of individuals engaged in postdoctoral training in science and engineering in the United States remained at about the same level between 1977 and 1981, the proportion of postdoctoral trainees of foreign origin increased in many fields. For example, at doctorate-granting institutions in the field of physics, this proportion grew from 34 percent in 1977 to 46 percent in 1981.[15] Foreign engineers represented about 68 percent of the total number of postdoctoral trainees in 1981, up from 53 percent in 1977. However, their total number declined during this time, from 1,200 to about 1,000.[16]

Expanding enrollment of foreign students in recent years has clearly offset declines that might have otherwise occurred in total U.S. higher education enrollments. Numerous issues arise, however, from the possibility of continued high rates of participation of foreign students in U.S. science and engineering education. For example, one of these concerns is whether graduate programs are relevant to the unique educational needs and expectations of the foreign students.[17]

S/E Faculty and Staff

An important series of indicators of the state of the Nation's academic science programs may be the number and attributes of scientists and engineers employed within this segment of the economy. The significance of the educational sector as it relates to the S/E labor market is underscored by the fact that in 1981, almost 30 percent of all scientists and 5 percent of all engineers in the United States were employed by educational institutions (primarily colleges and universities), as were more than one-half of all doctoral level scientists and engineers combined.

Of the 3.1 million employed scientists and engineers in 1981, 548,000 were in educational institutions. Since 1976, the number of S/E's employed in educational institutions has increased at an average annual rate of about 5.5 percent, somewhat less than the 8 percent annual growth registered by the industrial sector over this period. (See figure 5-4.)[18]

[13]See ref. 18.

[14]See ref. 51.

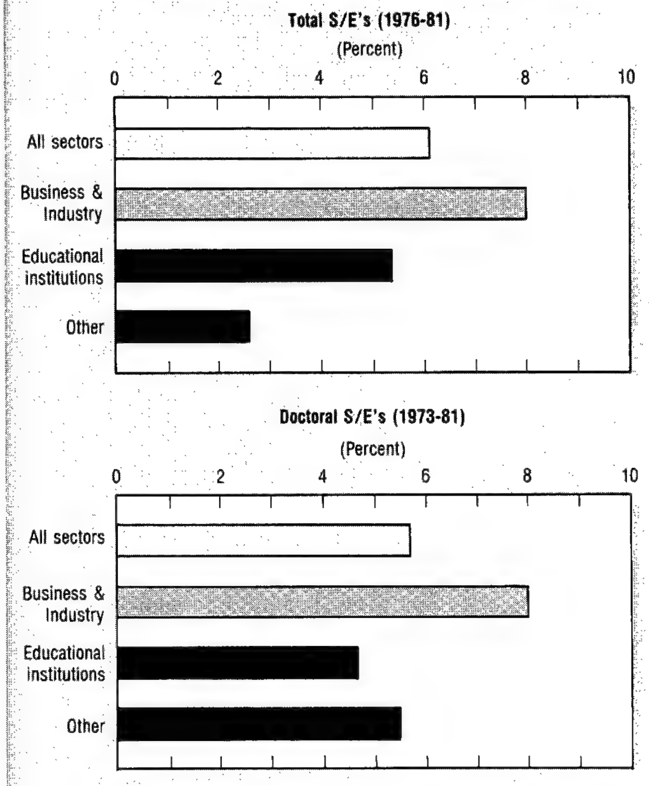
[15]See ref. 18.

[16]See chapter 1 of this report for a further discussion of foreign participation in postdoctoral training.

[17]In a survey involving 93 graduate institutions, U.S. faculty expressed concern that foreign students may not be able to transfer much of their scientific and technical knowledge to their home countries owing to the lack of adequate equipment, cultural differences, resistance to the ideas of professionals trained outside the home country, and the nonapplicability of theoretical knowledge to the conditions in the home country. See ref. 21. See also ref. 69 for a more general discussion of the role of the university in the international transfer of technology.

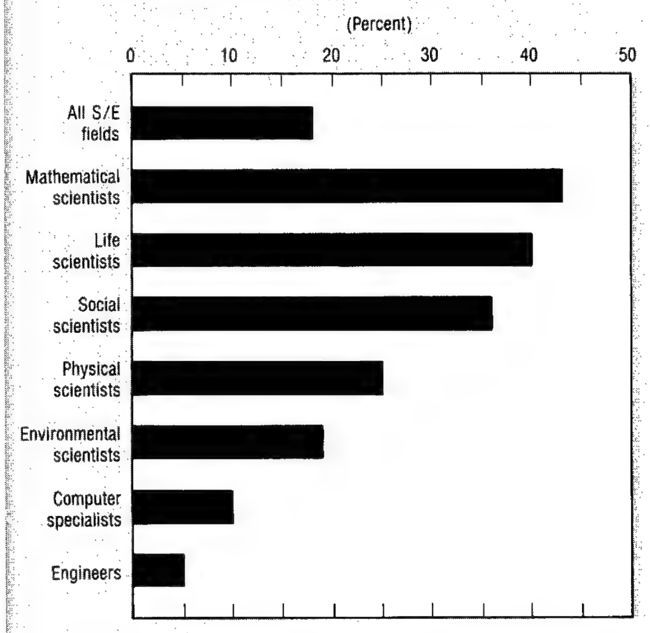
[18]For a discussion of recent trends in the U.S. science and engineering labor force, see also chapter 3 of this report.

Figure 5-4
Annual rate of growth in employment of scientists and engineers by sector of employment: selected years



See appendix tables 3-10 and 3-11. Science Indicators — 1982

Figure 5-5
Share of all S/E's employed in educational institutions by field: 1981



See appendix table 3-10. Science Indicators — 1982

This slower pattern of growth was also characteristic of doctoral scientists and engineers. Between 1973 and 1981, academic S/E's at the doctoral level grew at an average annual rate of about 4.5 percent, one percentage point below the overall growth rate for all doctoral S/E's. The lower rate of growth in academic employment was offset by industrial employment which increased at an average annual rate of 8 percent during this period.

The importance of the educational institutions in S/E employment varies substantially by field. For example, for all degree holders combined, educational institutions employed about 5 percent of the engineers in 1981 but more than 40 percent of the mathematical and life scientists in the Nation. (See figure 5-5.) A relatively large share of social scientists (including psychologists) were also employed in educational institutions (about 38 percent). As with engineers, only a small fraction of the Nation's computer specialists were so employed. For example, engineers and computer specialists account for only about one-fifth of all S/E's employed in educational institutions, but they comprise about four-fifths of the S/E's in industry.

Field variability is also evident in the case of doctoral degree holders; about one-third of the engineers, but a larger fraction of the doctoral scientists in the Nation (about 83 percent for all science fields combined), were employed in educational institutions in 1981. Again, the employment of computer specialists was similar to that of engineers and much less concentrated in this sector than, for example, mathematical and social scientists.

Variability in employment growth across fields reflects a variety of factors including research and development (R&D) funding patterns, academic course load requirements, S/E doctorate production rates, the impact of industrial recruiting competition in certain fields, and shortages of tenure-track faculty openings within many academic disciplines. An examination of these factors as they affect academic engineers illustrates the nature of reported concerns regarding the sufficiency of engineering faculty at the present time and in the near future.[19]

About one-tenth of the full-time engineering faculty positions were vacant at the beginning of the 1980-81 academic year, although by fall 1981 the number of vacancies had declined to 9 percent of the 18,000 full-time engineering faculty positions.[20] In this respect, about 9 in 10 engineering colleges reported a decrease in their ability to staff full-time positions during the past 5 years, attributing much of the problem to the reduced numbers of new engineering doctorates awarded and increased competition from industry in hiring them. This faculty shortage has occurred despite a 12-percent increase in academic R&D expenditures (in current dollars) in engineering between 1972 and 1980,[21] one of the more rapid R&D growth rates among all major S/E fields. Moreover, instructional needs in engineering have risen dramatically in recent years. For example, between fall 1976 and fall 1980, total full-time

[19]See ref. 23.

[20]See ref. 24. A recent survey of engineering deans by the Engineering College Faculty Shortage Project revealed that 9 percent of the 18,000 full-time engineering faculty positions were vacant in fall 1981, thus suggesting a "slight improvement" in the engineering faculty situation between fiscal years 1981 and 1982. See ref. 91.

[21]See ref. 76.

undergraduate enrollments in engineering grew at an annual rate of over 9 percent.[22]

The discussion of academically employed S/E's thus far has been based on employment across all educational institutions. The vast majority of academically employed doctorates, however, are in 4-year colleges and universities, about 96 percent in 1981. Of the balance, about two in three were employed by 2-year colleges. There has been little significant change in this distribution since 1973.

There has been a relative increase in part-time academic employment especially in 2-year colleges. This reflects a trend which has been underway since the early 1970's. A number of economic and demographic factors contributing to this effect have been identified, including the need for flexibility in adjusting to uneven rates of growth in enrollments in science and engineering fields, as well as academic salary levels in some S/E fields (notably engineering and computer science) that are not competitive with industry and the greater need in some fields to have teachers with industrial experience. Between 1980 and 1981, the number of part-time employed faculty in mathematical and computer science fields increased by 19 percent and in engineering by 7 percent as compared with increases of 4 percent and 2 percent in full-time positions for these fields, respectively.[23]

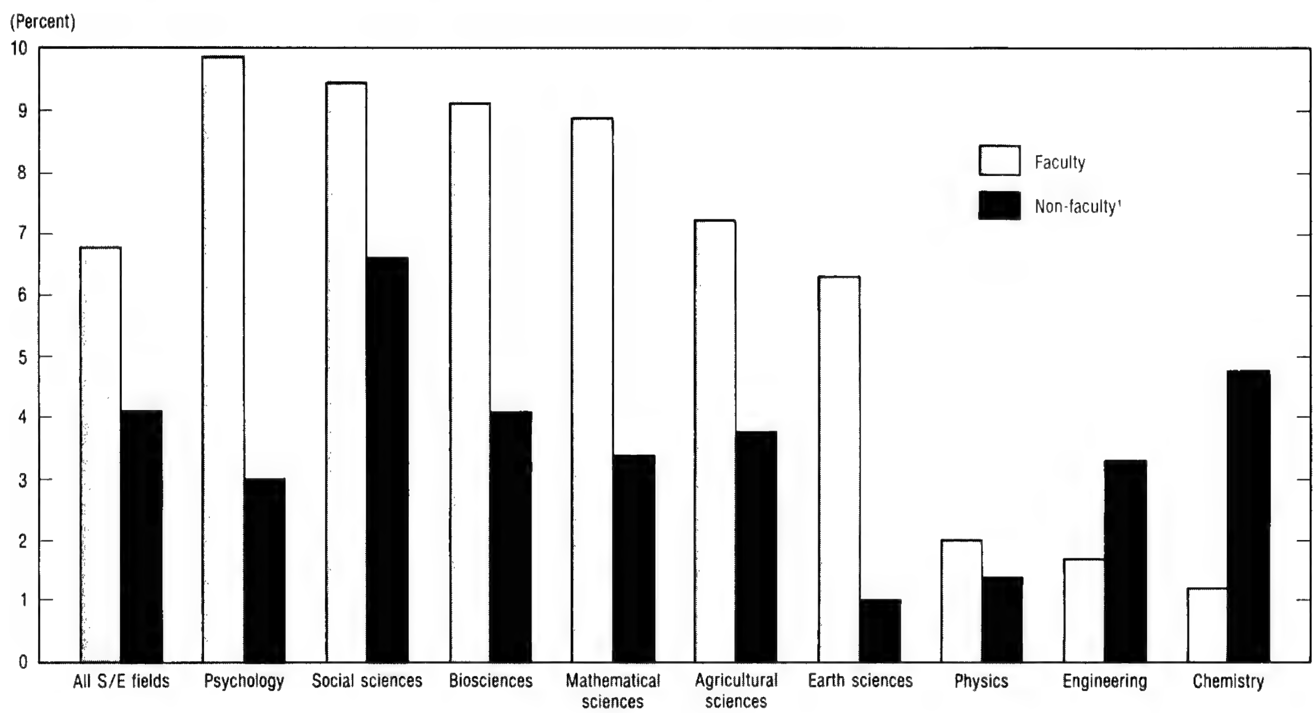
The changing patterns of academic employment during the 1970's have produced changes in types of academic staff appointments, with greater increases in nonfaculty positions than in faculty staff during the period. Between 1973 and 1979, for example, nonfaculty positions (excluding postdoctoral appointments) grew at an average rate of about 7.8 percent per year as compared with an average annual faculty growth rate of 4.1 percent.[24] The increase in nonfaculty staff when both postdoctoral appointments and other nonfaculty staff appointments are included was estimated to be 6.8 percent annually between 1973 and 1979.[25] The rapid growth in postdoctoral appointments which occurred during the 1970's appears to have slowed considerably; in 1981, the number of S/E postdoctoral appointees was estimated to be about 10,500, an increase of only 300 since 1979.[26] Although the ratio of faculty to nonfaculty staff differs subtantially among S/E fields, the relative increase in nonfaculty S/E staff was observed in all fields except chemistry and engineering. (See figure 5-6.)

The slower growth in faculty staff has resulted in a decline in the proportion of young faculty in science and engineering departments. The proportion of recent doctorates—those having earned their degrees within the past 7 years—on the full-time faculty of S/E departments in

[22]See ref. 25.
[23]See ref. 19.

[24]This includes doctoral research staff, that is, those scientists and engineers who are neither postdoctoral appointees nor members of the faculty but who are principally engaged in research. See ref. 29.
[25]*Ibid.*
[26]See ref. 30.

Figure 5-6
Annual rate of growth in number of doctoral scientists and engineers by faculty status: 1973-79



¹"Non-faculty" includes both postdoctoral appointees and other non-faculty doctoral research staff.

SOURCE: National Academy of Sciences, *Postdoctoral Appointments and Disappointments* (Washington, D.C.: National Academy Press, 1981), pp. 69-78.

Science Indicators — 1982

doctorate-granting institutions has declined sharply, from 39 percent in 1968 to 28 percent in 1974 to 21 percent in 1980.[27] Some believe that this decline is adversely affecting the vitality of academic research.[28]

The potential for new faculty appointments, although dependent upon many factors, is to a large extent determined by the operation of university tenure systems. A recent study[29] has shown that, at the beginning of the 1978-79 school year, about two-thirds of the full-time faculty at 4-year colleges and universities held tenure, while another one-fourth were not tenured but in tenure-track positions. Less than 1 in 10 were in nontenure-track positions.

R&D Activities

Estimates for 1983 indicate that only 9 percent of all research and development performed in the United States is carried out in university laboratories.[30] However, nearly 25 percent of all research and nearly 50 percent of all basic research is carried out in these institutions. Our Nation's higher education system thus is an important contributor to the flow of research ideas and the generation of new knowledge, as well as the training of scientific and technical personnel.[31]

In the United States, virtually all separately funded academic research and development activities are carried out in doctorate-granting institutions. (See appendix table 5-4.) In 1981, these institutions accounted for 98 percent of estimated academic R&D expenditures. Between 1975 and 1981, expenditures for R&D at doctorate-granting institutions doubled in current-dollar terms, rising to a total of nearly $6.7 billion in 1981. Among these doctoral institutions, 100 typically account for about 85 percent of all academic R&D expenditures; nearly one-fourth of total expenditures reported in 1981 was spent by 10 institutions alone. (See table 5-2.)

National economic conditions may result in an increasing concentration of R&D expenditures among a small group of colleges and universities.[32] It is clear, for example, that there has already been a decline in R&D expenditures within baccalaureate institutions—from $26 million in 1975 to $25 million in 1981 (see appendix table 5-4), a decline of nearly 40 percent in constant-dollar terms.

However, as table 5-3 reveals, very little change has occurred in the relative concentration of total R&D expenditures among the 100 largest R&D institutions between 1975 and 1981. The top 10 R&D institutions still represent slightly more than 20 percent of total R&D expenditures, and the top 100 R&D institutions represent about 85 percent.[33]

Table 5-2. Relative distribution of R & D expenditures among doctorate-granting institutions by rank[1]: 1981

	Percent	
Ranking[1]	Total	Cumulative
First 10	22	22
11–20	14	36
21–30	11	47
31–40	8	55
41–50	7	62
51–100	22	84
All other	16	100

[1] Ranked by total R & D expenditures reported in 1980.

See appendix table 5-4.

Science Indicators—1982

Table 5-3. Relative concentrations of R & D expenditures by source of support and institutional rank[1]: 1975 and 1981

	Percent	
Source	1975	1981
All sources:		
First 10	22	22
First 20	37	36
First 100	85	84
Federal support:		
First 10	24	26
First 20	41	40
First 100	85	85

[1] Ranked by total R & D expenditures reported in respective fiscal year.

See appendix table 5-5.

Science Indicators—1982

The 100 doctorate-granting institutions that account for the vast majority of academic R&D activities did not emerge full-blown as R&D leaders, but arrived at their current status through the efforts of community leaders, administrators, and faculty dedicated to the growth of science and technology at those institutions. The decentralized nature of the academic science system in the United States also helped by inducing a kind of competition, which according to some analysts[34] is responsible not only for the emergence of these research institutions but also for American science being elevated to its preeminent position today in world science and technology.[35]

In 1981, the 100 leading R&D institutions reported $5.6 billion in combined R&D expenditures.[36] These institu-

[27]See ref. 4.

[28]See ref. 83.

[29]See ref. 31.

[30]This estimate excludes R&D activities conducted in university-affiliated federally funded research and development centers (FFRDC's). Even if expenditures for those research centers are included in the calculation, the share of national R&D expenditures represented by total university R&D activities only rises to 11.5 percent. See chapter 2 for a more complete comparison of national support for university-based R&D with other sectors.

[31]See ref. 36.

[32]See refs. 32, 33, 34, and 36.

[33]See chapter 2 for a fuller discussion of anticipated trends in national support for academic research and development.

[34]See refs. 35, 36, and 37.

[35]As modern scientific laboratories have been established and gained visibility, students and faculty have sought to associate themselves with those programs contributing in turn to the productivity of these R&D laboratories. A recent study by the National Academy of Sciences, for example, has shown that the reputation of a science program often correlates quite well with the total number of faculty in that program, although this relationship varies across disciplines. See ref. 70.

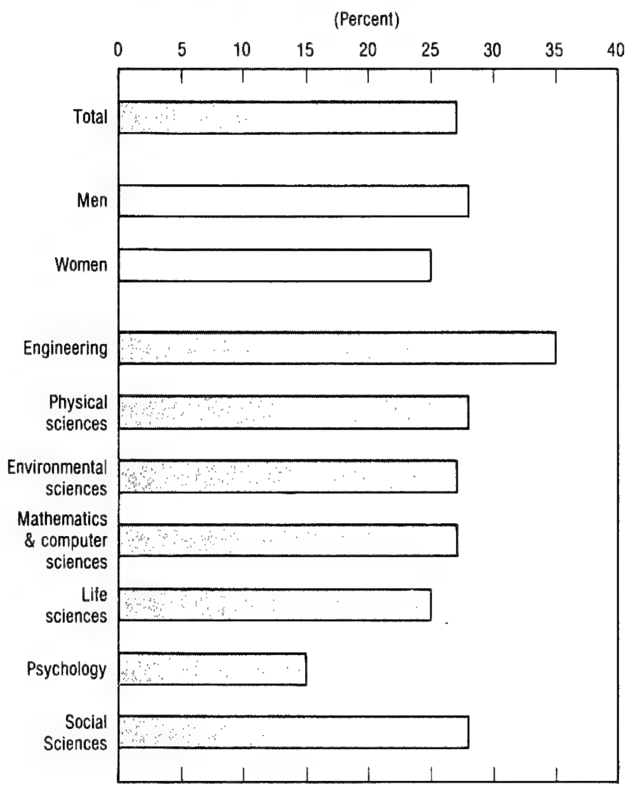
[36]A number of studies have analyzed the dependency of leading research universities on R&D support. Among the more recent are refs. 8, 33, and 37. See, also, refs. 89, 92, 98, 99, and 101.

tions derive most of their R&D funds from Federal sources. (See appendix table 5-6.)

The top 20 R&D institutions represent less than 10 percent of the total number of institutions offering science and engineering degrees. Yet, in 1980, these 20 accounted for nearly 27 percent of all full-time S/E graduate students, although differences exist across fields of science and engineering. (See figure 5-7.) Furthermore, approximately 38 percent of all postdoctorals worked in the laboratories of these 20 institutions in 1980. (See appendix table 5-7). Nearly 30 percent of all foreign students enrolled on a full-time basis in science and engineering were registered for study in one of these 20 universities.

Not only are these 20 R&D institutions larger than most doctorate-granting institutions on average, but they have also made greater gains in the growth of full-time science and engineering graduate enrollments than have most doctorate-granting institutions. (See appendix table 5-7.) Between 1977 and 1980, total full-time graduate enrollment in S/E fields grew by nearly 10 percent in the 20 largest R&D institutions, in contrast to the 4 percent growth observed in doctorate-granting institutions overall. Only in the field of psychology was an overall decline observed in full-time graduate enrollments regardless of institutional R&D level.[37]

Figure 5-7
Relative concentration of full-time S/E graduate enrollment in the top 20 R&D doctorate-granting institutions[1]: Fall 1979



[1]Ranked by total R&D expenditures in Fiscal Year 1980.
See appendix table 5-7. Science Indicators — 1982

Teaching Mission

Our Nation's colleges and universities contribute to the excellence of American research by maintaining vigorous, productive laboratories and by continuing to graduate skilled scientists and engineers who work in a variety of settings. Another primary function these institutions serve is introducing students from a wide variety of disciplines to the theories and methods of science.

While much attention is rightly being given to the quality of precollege science and mathematics education,[38] the role of science in the college education of the nonscience student is also important. After all, college may be the last opportunity for many individuals to gain an important formal introduction to the science and technology needed in this increasingly technological society.

One way in which students gain access to science at the college level (besides majoring in the subject) is through general education requirements.[39]

Most 4-year colleges and universities today require the study of science as a component of undergraduate education. Nonetheless, as table 5-4 shows, despite the fact that advances are being made in science, students complete college today with less coursework in science than that required of graduates 15 years ago. For example, in an institution requiring 125 credit hours for graduation, students can meet the 9-hour natural science requirement by taking a 1-year course or two half-year courses in science. In contrast, graduates 15 years ago were required to take nearly 12 credit hours of science studies.[40]

While the total number of general education requirements in the sciences has declined, the number and variety of courses in science and engineering for non-S/E majors has proliferated.[41] A recent survey of 215 4-year colleges and universities showed that 11 percent of the 6,200 undergraduate courses in physics—nearly 700 courses—were available to nonscience majors.[42] Many of these, of course, are

[37]The decline in full-time graduate enrollment in psychology may be related to a decline in the availability of graduate student support. See ref. 38 for a fuller discussion of recent changes in graduate training support and enrollment trends in psychology and related behavioral science fields, and ref. 95 for a discussion of the impact of changing patterns of research support on the pool of available behavioral personnel.

[38]The National Science Board of the National Science Foundation launched the Commission on Precollege Education in Mathematics, Science and Technology in 1982, which has been charged to analyze, among other things, the ways in which the declining quality in mathematics and science instruction in our nation's elementary and secondary schools can be reversed. See refs. 107 and 109, and such recent studies on the topic as refs. 39, 40, 41, and 42. Also see Chapter 3, Science and Engineering Personnel, for a discussion of the role of precollege education in the production of scientists and engineers.

[39]"General education" is a movement that has its origins in the early part of this century. It attempts to reintroduce into the undergraduate curriculum the concept of a well-rounded, liberal education at a time when the undergraduate curriculum has become fragmented and narrowly focused. See, for example, ref. 12; ref. 14, pp. 34-38; and refs. 43 and 90.

[40]Several studies that have looked into this issue include refs. 12, 14, and 44.

[41]See ref. 14, p. 42, and ref. 45.

[42]See ref. 14.

Table 5-4. Proportion of undergraduate education devoted to general education and to natural science requirements[1]: 1967 and 1980

Requirement type	Percent 1967	1980
General education	43.1	33.3
Natural sciences as a proportion of general education	21.0	20.7
Natural sciences as a proportion of total undergraduate requirements	9.1	6.9

[1] Based on fall data for four-year colleges and universities.

SOURCE: National Research Council, *Science for Non-Specialists: The College Years* (Washington, D.C.: National Academy Press, 1982), p. 39.

Science Indicators—1982

introductory science courses designed for majors and nonscience majors alike.

The effort to offer courses to nonscience majors is not uniform when analyzed by field or by institution. Physics departments in research universities, for example, are much more likely to offer separate introductory subject matter courses for nonscience majors than are physics departments in liberal arts colleges. Furthermore, while a number of doctoral institutions have set about designing courses to introduce nonscience majors to the computer sciences through specialized instruction, very little has been done by liberal arts colleges to date. (See appendix table 5-8.)

Computer education has become increasingly important in higher education in several ways. Computers can serve as research tools in such roles as simulators or as systems to make complex mathematical models possible. Computers assist academic administrators in developing campus-wide schedules or generating the payroll. Computers can aid instruction by serving as tutors—letting students work at their own pace—or by supplementing lectures with preprogrammed exercises or drills that extend the learning process beyond the lecture hall.[43] Indeed, a small number of academic institutions require all their undergraduates to purchase their own computers.

The number of institutions of higher education estimated to have access to computers doubled between 1965 and 1977.[44] By 1980, over 90 percent had computer services available, through their own computers or access to others through terminals.[45] Research institutions are more likely to have access, which might be expected in view of the high incidence of computer science courses observed in those institutions.

Several efforts are presently underway to enhance the availability of computers on campus. For example, the Alfred P. Sloan Foundation recently launched a new grants program to encourage liberal arts colleges to incorporate quantitative reasoning throughout the liberal arts curriculum. This program largely involves a special thrust in computer literacy.[46] Furthermore, under the leadership of the National Science Foundation, the private sector has been encouraged to donate equipment to educational institutions to permit them to get the equipment they need without jeopardizing their already strapped budgets.[47] Such efforts should be facilitated by certain provisions of the Economic Recovery Tax Act of 1981.[48] Section 222 permits liberal tax deductions for firms donating scientific equipment to colleges and universities.

RESOURCES FOR ACADEMIC SCIENCE AND ENGINEERING

The strength of the academic science and engineering enterprise in the United States is derived from generous levels of public and private support over the years, and from the talents of individuals who comprise the academic S/E labor force, as was discussed in the previous section of this chapter. R&D funding makes it possible to retain sufficient numbers of research staff, to purchase needed scientific instruments, and—as an ancillary benefit—to provide graduate students with important research experience. Academic scientists and engineers also depend on a variety of resources to aid them in realizing their teaching and research goals. Chief among these is up-to-date scientific instrumentation.[49] In addition to instruments, there are a number of other areas in which adequate resources have an important role in the work of academic S/E's. For example, investigators must have current periodicals and other literature at their disposal to keep abreast of developments in their fields and in related fields. Indicators that explore trends in the availability of these various resources have thus been gathered in this section.

Patterns of Support for Academic R&D

National support for academic research and development has reached historically high levels in current dollars in recent years. In 1983, an estimated $7.4 billion is expected to be spent in support of academic R&D. (See figure 5-8.) While expenditures in this area are large, and budgets continue to grow, inflation has taken its toll. In constant-dollar terms, the estimated 12-percent average annual growth rate for academic R&D in the 1960's slowed to 2.8 percent in the 1970's, and is estimated to have remained essentially constant since 1980.

There has been a significant shift from basic to applied

[43]See ref. 46, pp. 22-28, and ref. 47. In addition to computers, developments in the area of communications technology have the potential to meet new demands in the educational sector. These new information technologies include direct broadcast satellites, two-way interactive cable, video disks and videotape cassettes. See ref. 93.

[44]See ref. 10.

[45]See ref. 78.

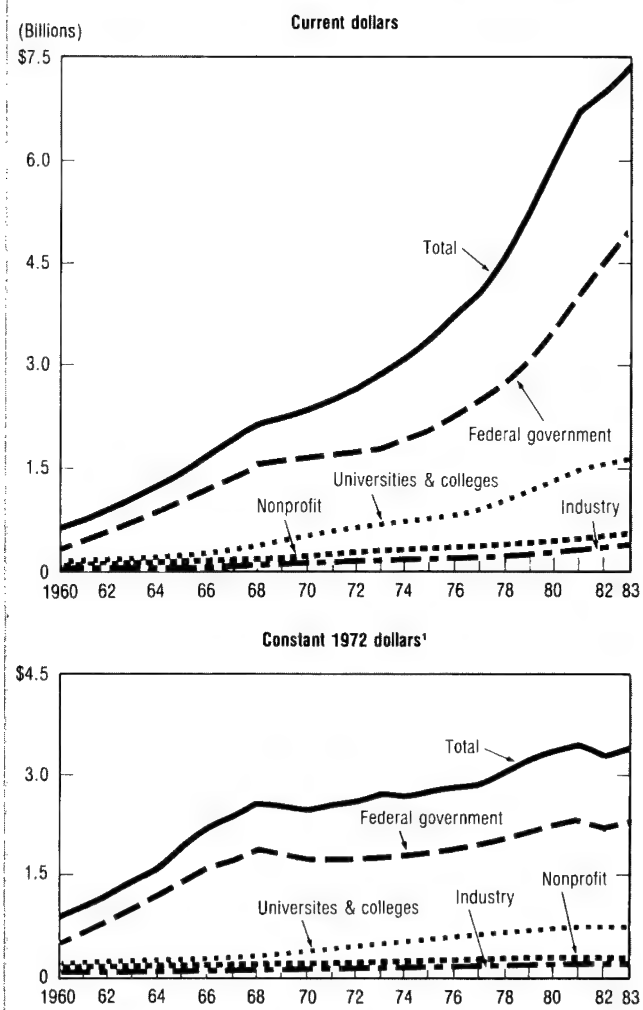
[46]See, for example, ref. 94.

[47]See ref. 48. A joint agreement has also been established between the National Science Foundation and the Defense Advanced Research Projects Agency (DARPA) that will allow qualifying universities to use the DARPA fast turnaround Very Large Scale Integration fabrication service at no cost as part of university-based research and education programs. See NSF Circular NSF 83-43.

[48]PL 97-34. Section 222 is concerned with the charitable contribution of scientific property used for research and training.

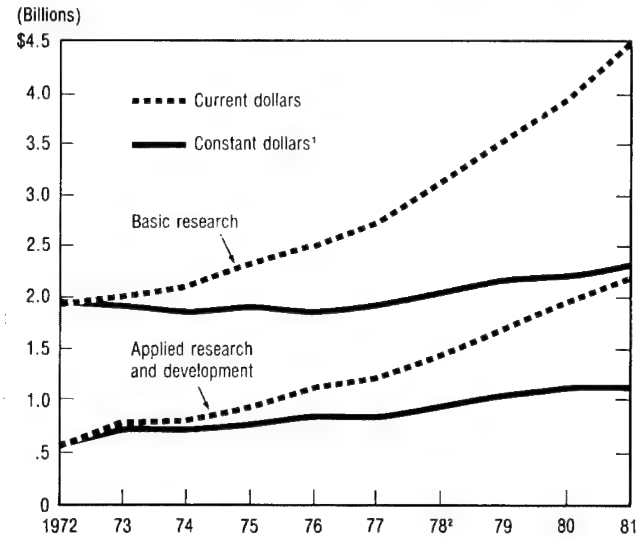
[49]See chapter 7, Advances in Science and Engineering, for an assessment of recent advances in instrumentation.

Figure 5-8
National expenditures for academic R&D by source



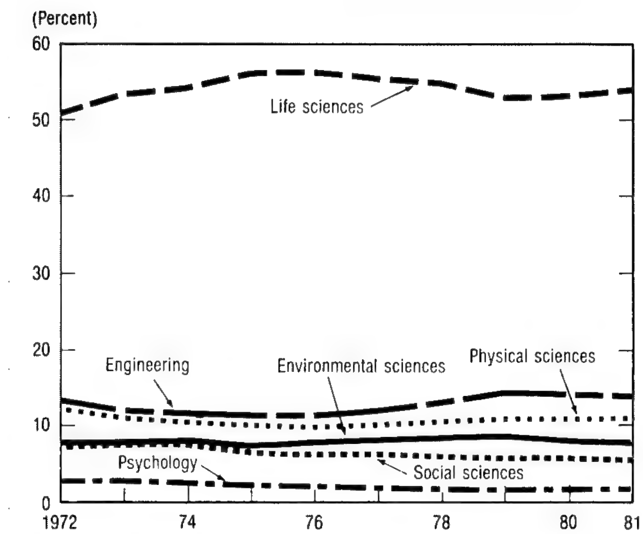
¹GNP implicit price deflator used to convert current dollars to constant 1972 dollars.
See appendix table 5-9. Science Indicators — 1982

Figure 5-9
National expenditures for academic research and development by character of work in doctorate-granting institutions



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Data were not collected by character of work in 1978.
See appendix table 5-10 Science Indicators — 1982

Figure 5-10
Relative distribution of R&D expenditures at colleges and universities for selected fields



See appendix table 5-11 Science Indicators — 1982

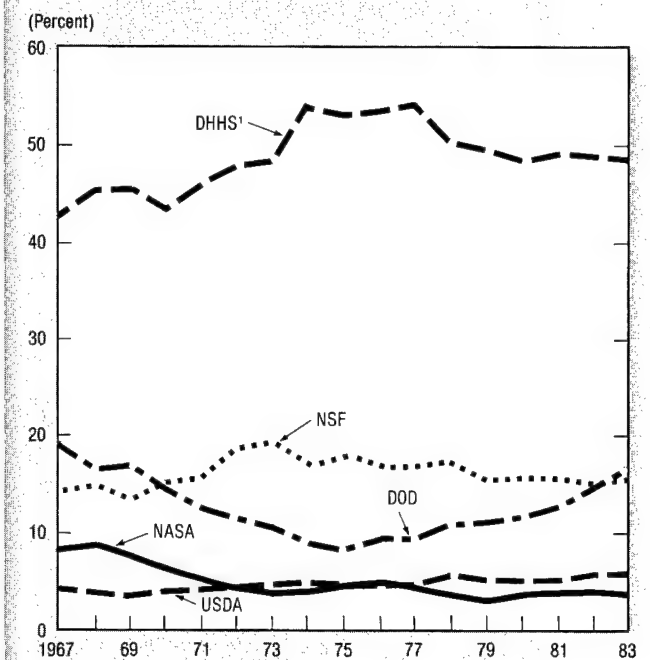
research and development in our Nation's colleges and universities between 1972 and 1981. Although about two-thirds of the academic R&D expenditures in doctorate-granting institutions[50] represented support for research directed toward fundamental scientific knowledge in 1981, down from a level of three-fourths in 1972 (see figures 5-9 and 5-12), expenditures for applied research and development were estimated to have grown at an average annual rate of 7.6 percent in constant dollars between 1972 and 1981—six times the rate reported for basic research support.

Among the fields of science and technology, the life sciences represent the largest share of academic expenditures for research and development. (See figure 5-10.) At a level of approximately 54 percent of total academic R&D expenditures, this area eclipses the proportion evident in the next cluster of fields: engineering (14 percent), physical sciences (11 percent), and environmental sciences (8 percent).

Federal obligations for academic research are distributed in much the same way by field as the research expenditures reported by academic institutions. (See appendix table

[50]Doctorate-granting institutions account for over 98 percent of total R&D expenditures. See appendix table 5-4.

Figure 5-11
Relative distribution of Federal obligations for R&D in universities and colleges by selected agencies



[1]Includes the education component of HEW through 1978.
See appendix table 5-13.

Science Indicators — 1982

5-12.) This may well be expected since Federal funds represent a substantial portion of academic R&D expenditures, about two-thirds of the total. (See appendix table 5-10.)

A noticeable decline for both the social sciences and psychology is evident in the share of total Federal academic research obligations they represent. Social sciences declined from 5.8 percent to 3.1 percent between 1973 and 1983, and psychology from 2.9 percent to 2.5 percent (see appendix table 5-12), as the growth in Federal research support in many fields outpaced that for the social sciences and psychology. As a percent of total academic R&D expenditures, social sciences funding declined from 7.6 percent in 1973 to 5.2 percent in 1981, and from 2.5 percent to 1.8 percent in psychology during that same period. (See appendix table 5-11.)

The distribution of Federal obligations for academic research and development can also be analyzed in terms of sponsoring agencies. As figure 5-11 shows, the Department of Health and Human Services (DHHS)—at a level of 48 percent—leads the agencies in terms of the proportion of all Federal R&D obligations it provides. The National Science Foundation (NSF), Department of Defense (DOD), U.S. Department of Agriculture (USDA), and National Aeronautics and Space Administration (NASA) each represent somewhere between 6 and 17 percent of Federal R&D obligations to academia.

The DOD has gained substantially in the share of Federal academic R&D obligations it has contributed in the past few years. From a low of 8 percent in 1975, DOD's share is estimated to have risen to 17 percent in 1983.

The USDA also reveals some growth, from a low of 4 percent of total Federal academic R&D obligations in 1974 to nearly 6 percent in 1983. The USDA and the State Agricultural Experiment Stations are generally considered to be the principal partners in the performance of agricultural research. However, other research institutions with few ties to this system—such as many of our colleges and universities—are increasingly conducting research directly relevant to the solution of agricultural problems. A recent report jointly issued by the Rockefeller Foundation and the White House Office of Science and Technology Policy concluded that research project grants, awarded on a competitive basis, should be used as an incentive to attract the best scientific talent to agricultural problems "regardless of where that talent resides."[51]

A small but important number of universities, such as the University of California, serve as managers of federally funded research and development centers (FFRDC's).[52] These centers have come to occupy a critical role in the national research and development effort.[53] Because FFRDC's often share faculty with science and engineering departments and make advanced research facilities available to investigators on a local as well as a national basis, it is instructive to consider how trends in the growth of R&D expenditures for these FFRDC's compare to national R&D expenditures for our Nation's universities and colleges. As figure 5-12 reveals, some interesting relationships exist. For example, while basic research expenditures in constant dollars grew at both doctorate-granting institutions and university-affiliated FFRDC's between 1972 and 1981, those reported by the FFRDC's grew faster—thus increasing the share of basic research expenditures represented by the work of those institutions. (See appendix tables 5-10 and 5-14.) Constant-dollar expenditures for applied research and development for these two performers, on the other hand, reveal quite similar growth patterns. Much of the growth in basic research expenditures in these university-affiliated FFRDC's after 1977 is related to substantial expansion of basic research support at three facilities: the Plasma Physics Laboratory (Princeton University), the Jet Propulsion Laboratory (California Institute of Technology), and the Lawrence Berkeley Laboratory (University of California).[54]

[51]See ref. 81.

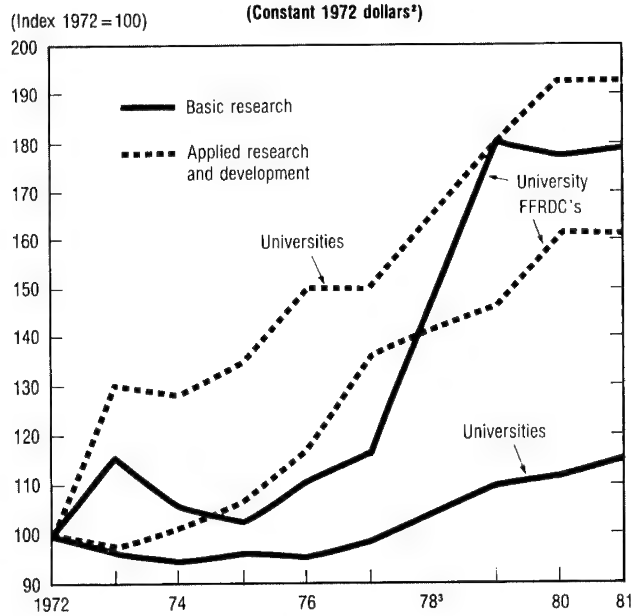
[52]To be classified as an FFRDC, an organization primarily performs basic research, applied research, development, or management of research and development on direct request of the Government or under a broad charter from the Government. An FFRDC is also organized as a separate entity within a parent organization, receives its major financial support (70 percent or more) from the Federal Government, has or is expected to have a long-term relationship with its sponsoring Federal agency, is established in such a way that most or all of the facilities are owned or funded by the Government, or has an average annual budget of at least $500,000. See ref. 84, p. 16. The NSF Division of Science Resources Studies has also adopted a new categorization scheme for listing FFRDC's based on the recommendations of a Federal interagency task force. Four categories are used: research laboratories; R&D laboratories; study and analysis centers; and system engineering/system integration centers. See ref. 106.

[53]See appendix table 5-15 for a list of these university-affiliated FFRDC's and the relative distribution of Federal R&D obligations. A number of studies have been conducted in recent years aimed at strengthening the role of the FFRDC and other Government laboratories in the national R&D effort. See, for example, refs. 82, 102, and 108.

[54]Based on unpublished data provided by the University and Nonprofit Institutions Studies Group, NSF.

Figure 5-12

Relative growth of R&D expenditures in university-affiliated FFRDC's[1] and doctorate-granting institutions for basic research and for applied research and development



[1]University-affiliated federally funded research and development centers.
[2]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[3]Data not collected by character of work in 1978.
Based on appendix tables 5-10 and 5-14.

Science Indicators — 1982

About 63 percent of the academic R&D expenditures in the physical sciences in 1981 were spent through university-affiliated FFRDC's.[55] Furthermore, this ratio grew from a level of 58 percent in 1972. Other fields which demonstrate that a sizable share of academic R&D expenditures were expended through FFRDC's in 1981 include: mathematical and computer sciences (51 percent in 1981); engineering (41 percent); and environmental sciences (26 percent). Clearly, the FFRDC's have come to play an important role in university research, underscoring all the more the need to enhance cooperative arrangements between these two performers.[56]

[55]The relative distribution of R&D expenditures by field of science in university-affiliated FFRDC's and doctorate-granting institutions is based upon information provided in appendix tables 5-10 and 5-14. It must be remembered, however, that when comparing the distribution of R&D funds between these two performing sectors, many of the 19 university-affiliated FFRDC's differ in function from university-based laboratories. There are those FFRDC's, for example, whose work largely represents development activities related to national security interests. It should be noted that academic R&D expenditures reported in other sections of this chapter do not include data on R&D expenditures at university-affiliated FFRDC's. See, for example, footnote 30.

[56]A source of concern in some quarters is that much more could be done to enhance research cooperation between these two performers of academic R&D. See, for example, ref. 102.

Scientific and Technological Activities

Analysis of the professional work activities[57] of academic scientists and engineers helps to quantify and characterize the Nation's scientific and technological effort. The functions of doctoral scientists and engineers are of particular interest because of their importance in strengthening United States leadership in science and technology.

Although there has been some decline, teaching activities continue to dominate the work patterns of doctoral S/E's in educational institutions.[58] In 1981, about 56 percent of doctoral S/E's reported teaching to be their primary work activity; research and development activities accounted for an additional 28 percent, including about 2 percent who cited the management of R&D activities. About 8 percent were engaged in non-R&D management activities, but other activities were only marginally represented among the academically employed.

Primary work activities of academic doctoral S/E's show a shift in work patterns during the 1970's. Between 1973 and 1979, a substantial decline was reflected in teaching activities (from 61 percent of the academically employed in 1973 to 52 percent in 1979) with accompanying increases in most other activities including R&D (see appendix table 5-16). During this period, the share of individuals reporting R&D activities (including the management of R&D) as their primary work activity increased from 27 to 32 percent. Much of this increase can be attributed to the sharp growth in S/E postdoctoral appointees (increasing by 80 percent) during this period.[59]

The relative decline in teaching as a primary activity during the 1970's appears to have reversed itself. Between 1979 and 1981, the proportion of individuals reporting teaching to be their primary work activity rose from 52 percent to 56 percent. During this period, the share working as managers and administrators, which had shown a steady relative increase during the 1970's, declined, including managers of both R&D and non-R&D activities. Total R&D activities (including the management of R&D), however, remained essentially stable with the decline in R&D management having been offset by an increase in research activities.

The activities reported by doctoral S/E's in academia show a pronounced field effect. The proportion of mathematical and social scientists primarily engaged in teaching activities is about double the ratio reported by life scientists.[60] (See figure 5-13.) Research and development activities show essentially the opposite effect with about one-half of all life scientists primarily engaged in R&D (including the management of R&D) as compared with less than one-sixth of the mathematical and social scientists.

[57]Information about the work activities of scientists and engineers has been collected through several types of surveys. One set of surveys collects information on the basis of the full-time equivalent number of individuals engaged in university and college R&D activities. Another set collects data from individuals who are asked to report their primary and secondary work activities. A third type of survey required individuals to maintain a log of the number of hours spent on various professional activities each week.

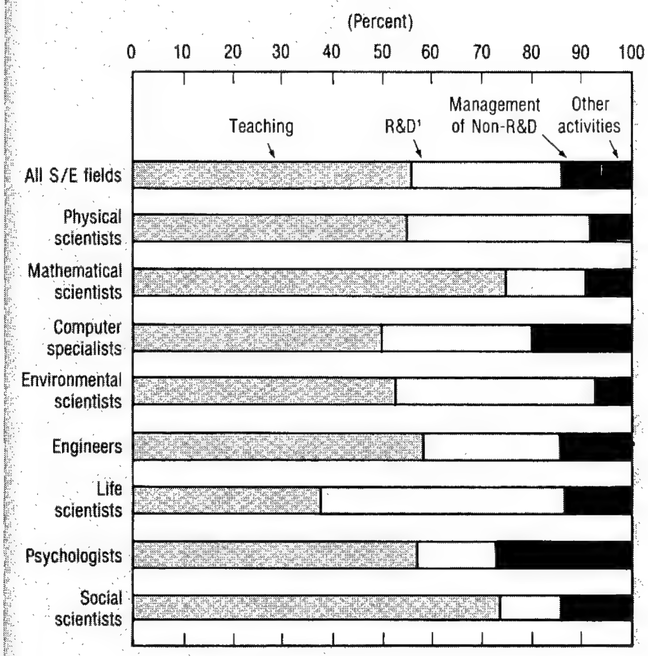
[58]See ref. 30.

[59]See ref. 52.

[60]Life sciences here, and throughout the chapter, include the medical sciences.

Figure 5-13

Primary work activities of doctoral scientists and engineers employed in educational institutions by field: 1981



[1]Including R&D management.

See appendix table 5-17.

Science Indicators — 1982

The distribution of academic R&D activities by character of work shows that, for all fields combined, about two-thirds of all academic R&D activities are accounted for by basic research and about one-quarter by applied research. (See appendix table 5-17.) The management of R&D was the major work of less than 1 in 10 and development activities reported by 1 in 50. This emphasis on basic research was evident especially in the physical, mathematical, and life sciences, but was lower in other fields, most notably among engineers and computer specialists who reported substantially greater involvement in applied research and development activities.

Despite the slowdown in academic employment opportunities since the mid-1970's, academic R&D as reflected by primary work activity data has grown steadily. Over the 1973-79 period, this growth rate averaged nearly 8 percent per year, three points higher than the growth rate of overall doctoral employment in educational institutions. Since 1979, however, the growth in R&D activity appears to have decelerated; between 1979 and 1981, the number of academic doctorates in S/E fields citing R&D as their primary work activity increased at a rate of less than 2 percent per year. This decline in growth is corroborated by other survey data. Based on data collected from doctorate-granting institutions, the full-time-equivalent (FTE) number of academic R&D scientists and engineers increased at an average annual rate of 4 percent between 1973 and 1978, but only 1 percent per year between 1978 and 1981. This decline in growth has been attributed to the increased utilization of graduate research assistants who may be offsetting full-time professional staff in academic R&D activities.[61]

The data thus indicate that the shift from teaching to R&D during the 1970's has slowed down. Nevertheless, a general increase in academic R&D activities since 1977 has been sufficient to offset relative declines in R&D activities by S/E's in other employment sectors. As a result, the proportion of doctorates for all sectors combined who reported R&D to be their primary work activity has remained constant at 44 percent since 1973.

A survey which collected log/diary records on the professional activities of full-time S/E faculty in academic year 1978-79 indicates that the average work patterns of S/E faculty at universities are substantially different from those at 4-year colleges.[62] For all fields combined, university faculty spent about one-third of their time on research activities[63] and another third on instructional activities, with the balance of their professional time devoted to a variety of tasks including public service, administration, and other professional activities as well as other outside income-producing activities.

The amount of time devoted to research by university faculty was about three times that of their colleagues at 4-year colleges. Almost all of this difference was accounted for by time spent on federally supported programs for research by university faculty.[64] Faculty at 4-year colleges devoted a larger proportion of time to instructional activities—about one-half of their total professional time compared with one-eighth time in research. The data further indicate that university faculty devoted an average of 48 hours per week to professional activities compared to 43 hours at 4-year colleges.

The data from this study also show that the time devoted to research and instructional activities varies across science and engineering fields, especially in respect to university faculty. Thus, faculty in the physical, environmental, and life sciences devoted more time to research than to instruction, whereas the opposite was found among faculty in psychology, social sciences, and mathematical sciences. In the field of engineering, instructional and research activities were essentially equal. This field-oriented pattern of emphasis on research vs. instruction is generally consistent with the field effects depicted by primary work activity data reported earlier.

Support for Graduate Education

The partnership between the Federal Government and higher education as far as the training of S/E's began in earnest with the establishment of the NSF fellowship program in 1952, two years after the establishment of the agency itself.[65] The National Defense Education Act of

[61]See ref. 28.

[62]See ref. 53.

[63]Data from this survey indicate that faculty spend about one-third of their total research time on nonsponsored research although this share varies by field and by type of institution.

[64]See ref. 72.

[65]The National Institutes of Health sponsored graduate training support as early as 1930 to develop a cadre of investigators who would conduct health research. As each institute was founded, research training became an integral component of each institute's operation. See ref. 38; and also ref. 54, pp. 18-19, and ref. 55.

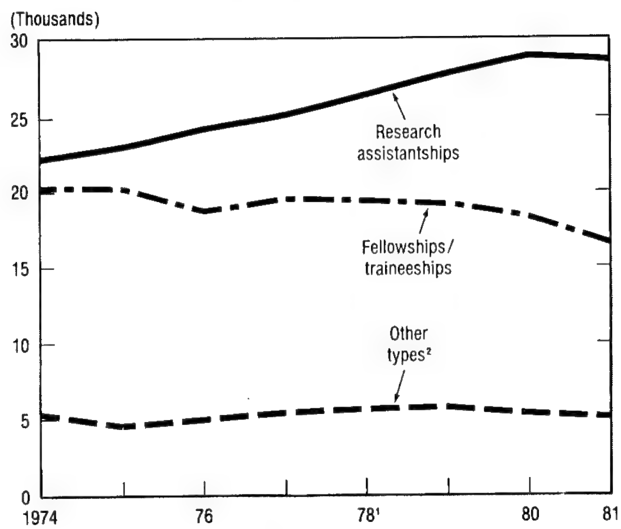
1958 promoted opportunities for undergraduate education in the sciences and engineering, and, together with dramatic increments in graduate student support at about that time, marked the beginning of significant Federal investment in support for science and engineering education.[66]

Federal fellowship and training grant support for full-time graduate education in S/E appears to be continuing the decline begun in the early 1970's. (See figure 5-14.) Opportunities for research training have grown, however, through research assistantships. Despite this growth, Federal support of full-time graduate S/E students declined from a level of 25 percent of all full-time graduate S/E students in 1974 to just over 21 percent in 1981, as full-time graduate S/E enrollment growth outpaced Federal graduate S/E support. (See appendix table 5-19.) The number of full-time graduate students receiving Federal support grew by only 0.8 percent on average each year since 1974, in contrast to the average annual growth rate of 2.6 percent for all full-time graduate science and engineering students. Excluding foreign sources of support, self-support seems to be taking up the slack. Self-support grew at an average annual rate of 3.5 percent between 1974 and 1981.

Despite the fact that efforts have been made in recent years to encourage private sector support for graduate training in the sciences and engineering,[67] the proportion of full-time graduate students reporting such outside support (other U.S.) remained at a level of approximately 6 percent between 1974 and 1981. (See appendix table 5-19.)

The rapid growth in support from foreign sources reflects the continued increase in the number of foreign students attending college in the United States in recent years. (See figure 5-3.)

Figure 5-14
Full-time S/E graduate students in doctorate-granting institutions by type of Federal support: 1974-81



¹Data were not collected in 1978.

²"Other" includes teaching assistantships.

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1981* (NSF 83-305). Science Indicators—1982

Scientific Instrumentation

Today's research in science and engineering requires sophisticated equipment. Advanced instrumentation enables scientists and engineers to measure the characteristics of physical phenomena at speeds previously unimaginable and at levels heretofore inaccessible to the human sensory system.[68] Indeed, entire theories and models of the physical world have been built around the advances made possible by improvements in scientific instruments.[69] The importance ascribed to up-to-date equipment in modern experimental methods is also reflected in the fact that a number of Nobel Prizes have been awarded in recent years precisely for the development of instruments or for methods of measurement.[70]

The chief source of funding for instrument purchases in the academic sector is the Federal Government. Almost two-thirds of the $420 million spent by universities for S/E research equipment in 1981 represented federally funded equipment expenditures.[71] Furthermore, increased funding has been proposed in fiscal year 1984 for university instrumentation to enhance productivity and excellence in research and training.[72]

Limited information is available describing the present state of scientific equipment in America's colleges and universities.[73] Recognizing the need for such data, the National Science Foundation (NSF) has been developing indices, correlates, or other suitable measures or indicators of the

[66]Numerous studies have addressed the recent history of Federal support for graduate education in the sciences and engineering. Among the more recent are refs. 2, 23, 56, and 85. The National Academy of Sciences has recommended that Federal support of graduate S/E education would more profitably be directed if long-range S/E personnel requirements were taken into account rather than the short-term behavior of the labor market as is often the case. See ref. 104, pp. 5-7 and 71-85. Furthermore, concerned about levels of indebtedness among students who continue to borrow funds to attend college, Congress established the National Commission on Student Financial Assistance as part of the Education Amendments of 1980 (PL 96-374). As part of its analyses (scheduled for release in the latter half of 1983), the Commission has addressed the issue of the sufficiency of support for graduate and professional education and the role of the Federal Government in providing such support.

[67]The private sector has stepped up its efforts to enhance graduate training support in the sciences and engineering. Corporate support of all educational activities reached an estimated $1.1 billion in 1981. This is an increase of $110 million (or 10.6 percent) over 1980 levels. See ref. 57, p. 2. A recent study by the National Center for Higher Education Management Systems suggests, however, that voluntary support for student financial aid has not kept pace with inflation. See ref. 96, p. 94. The contribution of education to overall economic growth and the implications for student training support have been the subject of a number of recent studies. Among these are refs. 86, 87, and 88.

[68]See chapter 7 for examples of the contributions of advanced scientific instrumentation to research and development in recent years.

[69]See, for example, refs. 58 and 59.

[70]Within the past three decades, the Nobel Prize in physics has been awarded for the development of such instruments as the phase-contrast microscope, the transistor, the bubble chamber, the laser, the holographic method, and the chromatograph. See ref. 64 and chapter 7.

[71]See ref. 77, p. 4.

[72]See ref. 103.

[73]See refs. 60, 61, 62, 63, 64, and 104.

status of scientific instrumentation in the United States. Interest in these indicators is also evident in the Congress which has encouraged the NSF to further develop such measures.[74]

In 1981, a preliminary study of 38 institutions, selected from the largest academic R&D performers, revealed an apparent relationship between annual R&D expenditures and the number of large equipment items in a college's laboratory, that is, instruments costing at least $50,000. Large R&D performers reported 22 percent of their equipment items costing at least $50,000, while smaller R&D performers reported only 7 percent on average.[75] Investigators in organic chemistry departments reported the largest portion of instruments costing $50,000—27 percent—in contrast, for example, to only 7 percent in cell biology.[76]

In addition to an inventory of laboratories, there are several characteristics of research instrumentation that may be used potentially as indicators of need in this area. Just under half the instruments in the laboratories surveyed were less than 5 years old. (See table 5-5.) Only the electrical engineering and medical biology laboratories reported a clear majority of instruments under 5 years old. In each of the remaining fields analyzed, over 25 percent of inventory items were over 10 years of age.

The number of users is related to everyday wear and tear on instruments. Organic chemistry revealed the highest average number of users for both in-house laboratory personnel and other users. (See appendix table 5-20.) The wear and tear that comes with the comparatively heavier use of instruments in the organic chemistry laboratories studied may explain why organic chemistry also reported a proportionately higher percentage of "downtime,"[77] although it might also be related to the type of equipment used in those laboratories and switching from one user to another.

The data emanating from this feasibility study are important because they demonstrate that it is possible to quantify certain aspects of laboratory scientific equipment in a useful manner. The data should not be construed to represent the present state of equipment in U.S. academic laboratories, since the data merely serve as preliminary measures until a more systematic national survey is completed in the coming months.[78]

Research Libraries

For research and graduate education to be of the highest quality, students and faculty must have access to large, up-to-date research libraries.[79] While many American colleges have built libraries that serve as outstanding resources for research and learning, many face substantial problems in maintaining present inventories at a time of increasing costs and shrinking budgets. A recent analysis of 75 university libraries revealed that between 1970 and 1980 expenditures for library materials increased by 91 percent while the number of volumes added decreased by 23 percent.[80] Between 1976 and 1980, the top[81] research libraries continued to add new volumes to their collection at an average annual rate of 1.7 percent, although this rate varied across the following institutional groupings:

Library rank	Percent added
1-10	0.8
11-20	1.3
21-30	2.8
All 30	1.7

[74]See Public Law 96-44, Section 7, National Science Foundation Authorization Act of Fiscal Year 1980.

[75]See ref. 63. Survey respondents were asked to report on all items costing $5,000 or more; major equipment items such as accelerators were excluded from the study.

[76]See ref. 66.

[77]"Downtime" refers to instruments being unavailable for usage because of repair or routine maintenance.

[78]In the fall of 1982, NSF launched the National Survey of Academic Research Instruments and Instrumentation Needs with data collection to be completed in the summer of 1984.

[79]See refs. 67 and 97.

[80]These 75 research libraries were selected from members of the Association of Research Libraries. See ref. 71.

[81]Ranked on the basis of the total number of volumes in the collection at the end of the fiscal year. See ref. 68.

Table 5-5. Age of scientific equipment in academic laboratories by investigator discipline: 1981

Age of instruments in laboratory	Percent					
	Total	Cell biology	Organic chemistry	Solid state physics	Electrical engineering	Medical biology
5 yrs. old or less	49	43	49	47	59	55
6–10 yrs. old	26	29	25	24	19	38
11–15 yrs. old	16	16	15	18	18	6
Over 15 yrs. old	9	12	11	11	4	1

See appendix table 5-20.

Science Indicators—1982

Priority is evidently being given by these institutions to maintaining their collections. Indeed, estimated expenditures for books and materials at these top 30 research libraries grew at an average annual rate of nearly 3 percent after adjusting for inflation.[82]

Although the Nation's largest academic research libraries have managed to stay ahead of inflation in terms of budget size, a decline in the proportion of their collections that represent new acquisitions is evident. (See table 5-6.) Given the continuing constraints placed on academic fiscal resources, it appears likely that academic institutions having large collections will also be challenged in the coming years to sustain their growth, a problem which smaller research libraries have already confronted.

Table 5-6. Volumes added as a percent of total library collection for the top 40[1] academic research libraries: 1976 and 1980–82

	Percent			
Rankings[1]	1976	1980	1981	1982
First 10	3.2	2.9	2.5	2.3
11–20	3.5	3.1	2.1	2.2
21–30	3.9	3.7	3.1	2.8
31–40	3.9	3.5	3.0	3.2

[1] Ranked on the number of total volumes in the collection at the end of the year.

SOURCE: Association of Research Libraries, *ARL Statistics* (Washington, D.C.), annual series.

Science Indicators—1982

OUTCOMES OF ACADEMIC SCIENCE AND ENGINEERING

The goals of academic science and engineering are the generation and transmission of new knowledge through research, education, publication, and consulting. The indicators that have been gathered in this final section begin to explore how well academic science and engineering are meeting these goals. Indicators have been selected in three areas: growth in the patenting of inventions by academic institutions; knowledge transfer beyond the academic sector through the consulting process; and knowledge production through the literature base.

Patents Issued to Academic Institutions

An academic scientist or engineer is primarily interested in teaching and research and in participating in disseminating scientific knowledge through publication and related activities. The discovery and commercial application of an idea or an invention have been of secondary importance to faculty for the most part.[83] Changes in national research needs and opportunities for patenting of inventions have attracted an increasing number of academic institutions to the transfer of their research ideas into the marketplace. In addition, the problem of adequate resources for academic institutions has made them more interested in the potential economic gains through patenting.

Generally, academic inventions are brought into public use through licensing arrangements with industrial concerns.[84] The property licensed may occasionally include patent rights, and usually a royalty is charged. The license may also include such items as issue fees, minimum royalties, and safeguards to insure the widest possible use of the invention. Another practice in the handling of academic inventions is the use of patent management organizations[85] who usually share royalties with the institution after providing assistance to that institution in the patenting or licensing of an invention.

The number of U.S. colleges and universities with specific patent policies is not known, although most research universities are thought to have established patent policies and procedures.[86] However, it is clear from recent changes in Federal patent policy that a greater number of academic institutions will be stimulated by events to move toward establishing such policies.

Chief among these changes was the enactment of the Patent and Trademark Amendments of 1980.[87] Section 6 of this law established a uniform policy for assigning title to inventions made by small businesses or nonprofit contractors—including academic institutions—during Government-sponsored research. The primary objective of this law is to eliminate a number of individual Federal agency policies regarding the ownership of patent rights and to replace them with a uniform Government-wide policy which permits the issuance of exclusive rights to a would-be developer of a patent.[88] It is believed that this change will reduce administrative costs and provide contractors with an incentive to bring federally funded research to commercial use.[89]

The number of patents issued to academic institutions more than doubled between 1969 and 1980, increasing at an average annual rate of about 7.3 percent (see figure 5-15), although the total number of patents is still a very

[82] *Ibid* and earlier volumes in that series.

[83] See ref. 73, p. 26, and ref. 105, pp. 84-101.

[84] *Ibid.*

[85] The Research Corporation, for example, was established over 70 years ago to assist college faculty in the transfer of useful technology to the public sector. Other arrangements include autonomous institutions such as university-based research foundations, separate and distinct from the university, that assist university faculty in the transfer of ideas to the public sector. An example is the Wisconsin Alumni Research Foundation established in 1925. See ref. 74.

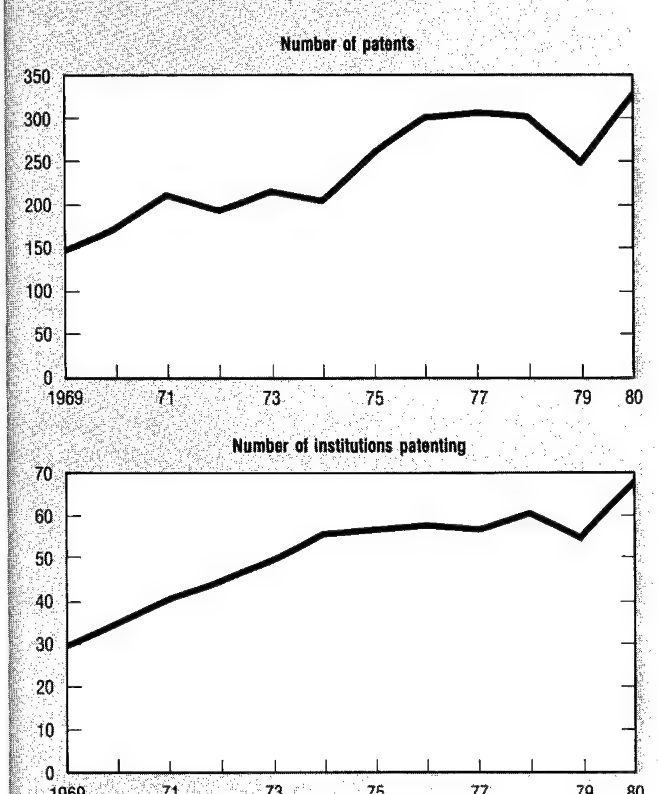
[86] For many years, the National Science Foundation required that an academic institution have a formal patent policy before entering into an Institutional Patent Agreement (IPA) with NSF when the possibility of a patentable idea or invention was clear. The National Institutes of Health similarly required institutions to have "technology transfer programs" before entering into an IPA.

[87] Public Law 96-517. Section 6 is sometimes referred to as the "Bayh-Dole Act."

[88] See ref. 75. This is not the first attempt to make Federal patent policies more uniform. In 1963, a Presidential Memorandum was issued by President John F. Kennedy on this subject and was revised and reissued in 1971 by President Richard M. Nixon. Most recently, President Ronald Reagan issued a memorandum directing Federal agencies to adopt and implement the same policies for all R&D contractors as those set forth in Public Law 96-517 (February 18, 1983).

[89] The recently enacted patent fees bill (Public Law 97-247) might also increase the number of patents issued to academic institutions because it lets universities get and maintain patents at half the cost imposed on most firms.

Figure 5-15
U.S. university patenting by date of grant



SOURCE: U.S. Patent and Trademark Office, unpublished data.
Science Indicators — 1982

small proportion of the total number of patents issued. The number of institutions to whom patents were granted also increased during that time, from an estimated total of 30 institutions in 1969 to approximately 70 in 1980.[90] The opportunities for patenting brought about by recent changes in Federal policies will undoubtedly contribute to the continued growth of patent activities in this sector. It is important to keep in mind, however, that although trends in the number of patented inventions can serve as an indicator of the output or level of accomplishment of academic R&D, the growth in the number of patents granted to academic institutions could more likely reflect the greater opportunity and interest evident in the past decade for universities to seek patents. Thus, this indicator does not necessarily reflect greater inventive activity on the part of academic investigators.[91]

[90]A substantial number of these patents were issued to such patent management organizations as the Research Corporation. Because the data do not permit a count of the number of institutions represented by such patent management organizations, the number of academic institutions involved in patenting is somewhat underestimated. However, the evidence of growth in the number of academic institutions presented in these data is not compromised.

[91]Compare this indicator, for example, with the treatment of industrial patenting activity found in Chapter 4 of this report.

Consulting Activities

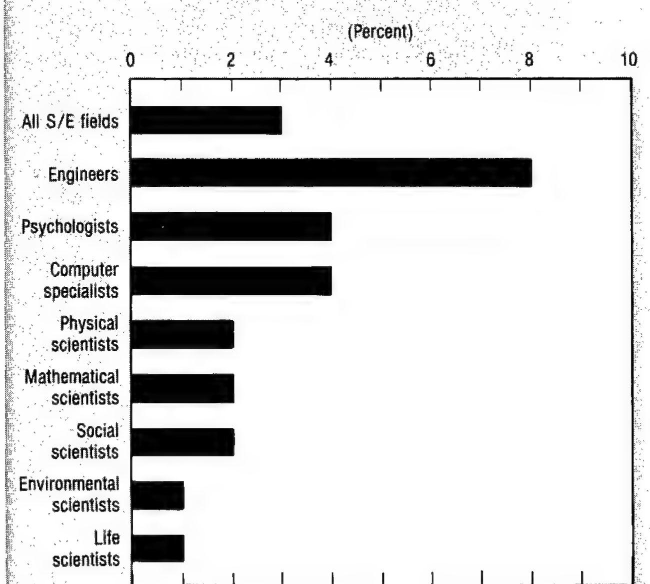
Evidence of current shortages in some S/E fields, as well as expectations of a decline in academic support from Federal sources have prompted efforts to promote an increased level of cooperation between the academic and private sectors, including the enhancement of the transfer of research information. One aspect of this information transfer process may be reflected by the consulting activities reported by academic S/E faculty staff. Based on a study of the professional activities of full-time S/E faculty at universities and 4-year colleges, about 3 percent of the work week was devoted to consulting activities. The extent of this activity varied among S/E fields and was highest among engineers (8 percent), psychologists (5 percent), and computer specialists (4 percent). (See figure 5-16.) The higher index of consulting activities in these fields is generally consistent with other data reflecting the primary and secondary work activities reported by academic doctoral scientists and engineers.[92] The higher demand for consulting services of academic engineers is related to their traditionally closer ties to industry.

Research Literature

An important aspect of academic science and engineering is the publication of research findings in scientific and technical journals. These publications are a vehicle for the culmination and communication of the research activities

[92]See refs. 30 and 72.

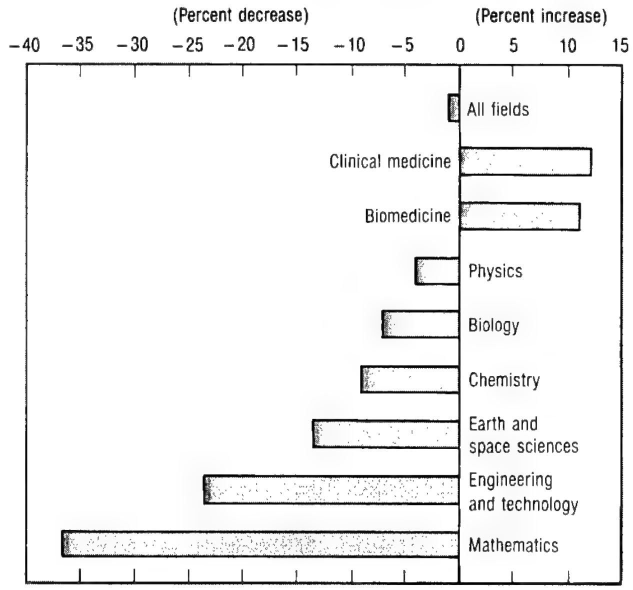
Figure 5-16
Percent of workweek devoted to consulting activities by full-time academic faculty in S/E fields: 1978/79



SOURCE: National Science Foundation, *Activities of Science and Engineering Faculty in Universities and 4-year Colleges: 1978/79*, (NSF 81-323), pp. 22-34.
Science Indicators — 1982

Figure 5-17

Percent changes in the number of science and technology articles[1] by U.S. college and university author's by field[2]: 1973 to 1980



[1]Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See appendix table 1-17 for the subfields included in these fields.
Based on appendix table 5-23. Science Indicators — 1982

of academic scientists and engineers, and contribute substantially to the growth of the scientific literature base.[93]

The research literature indicators presented in this section are largely based on articles, notes, and reviews from over 2,100 highly cited or influential journals. The same set of journals has been examined for the 1973-80 period so that longitudinal comparisons could be made without the artifact of a change in level of research coverage. Academic institutions are responsible for about two-thirds of these influential scientific and technical articles.

Overall, the number of an U.S.-authored articles found in this journal set declined by 5 percent between 1973 and 1980,[94] but U.S. articles by college and university authors declined overall only by 1 percent. Decreases in the number of articles occurred in six of the eight fields examined. (See figure 5-17.) Especially notable declines are evident in mathematics (37 percent), and engineering and technology (23 percent). These two fields also emerged as the only fields in which both U.S. and non-U.S. articles have declined in number between 1973 and 1980.[95] The annual number of journal-based publications by academic authors during this 7-year period rose only in the fields of clinical medicine (12 percent) and biomedicine (11 percent). Despite declines in the number of articles published in many of these fields, their influence has changed very little. (See appendix table 5-22.) Only in the field of physics did the ratio of the number of citations to the number of published articles decrease to a level of lesser influence as shown below:

Field	Relative citation ratio[96] 1973	1978
All S/E fields	1.04	1.05
Clinical medicine	1.02	1.03
Biomedicine	1.00	1.01
Biology	1.10	1.06
Chemistry	1.10	1.13
Physics	1.00	.91
Earth and space sciences	1.04	1.05
Engineering and technology	1.24	1.21
Mathematics	.99	.99

The distribution of scientific and technical articles by U.S. college and university authors also varies across fields when analyzed by institutional rank.[97] The first 10 institutions, based on publication counts, typically account for more than one-fifth of all academic-based articles, as shown below:

Field	Percent of articles by first 10 institutions
Earth and space sciences	32
Biology	29
Physics	27
Clinical medicine	26
Engineering and technology	26
Biomedicine	24
Mathematics	23
Chemistry	19

The first 100 institutions in each of these fields produced over 80 percent of the academic-based publications, although differences are evident across fields. (See appendix table 5-25.) The relative distribution of these research articles by institutional rank has remained quite stable since 1973.

Changes have occurred in the number of scientific and technical articles written by U.S. college and university authors when analyzed by character of work. As figure 5-18 reveals, the number of academically authored articles from the more basic research journals increased between 1973 and 1980 in only two of the eight fields analyzed,

[93]Approximately 68 percent of all the articles written by U.S. scientists and engineers in 1980 represent the work of academic investigators. See appendix table 5-22.

[94]See appendix tables 1-18 and 5-22 for a summary of the publication and citation trends for all U.S. authors, and the chapter on "International Science and Technology" for a discussion of world trends. The comparisons here do not reflect, of course, the growth of publications resulting from articles published in journals that have appeared since 1973 or which are not considered "influential" as the term is used here. For further information on the evaluation of bibliometric data, see ref. 79.

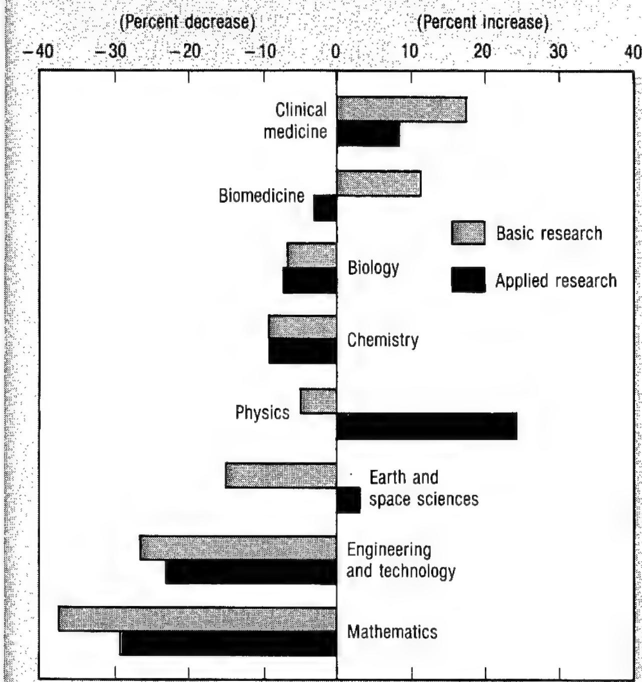
[95]See appendix table 1-16 for a comparison of U.S. and world scientific and technical articles.

[96]A citation ratio of 1.00 would mean that the cited sector received a share of citations equal to its share of published articles.

[97]Institutions are ranked by number of articles published in each field of science examined here.

Figure 5-18

Percent changes in the number of scientific and technical articles[1] by U.S. college and university authors by field[2] and character of research: 1973 to 1980



[1]Based on about 100,000 of the articles, notes and reviews per year by U.S. authors in over 2,100 of the influential journals of the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]See appendix table 1-17 for the subfields included in these fields.

NOTE: See appendix table 5-26 for examples of the more basic and more applied journals.

Based on appendix table 5-25.

Science Indicators — 1982

namely clinical medicine (18 percent) and biomedicine (12 percent). Substantial declines in the publication of articles in more basic journals were evident in the fields of mathematics (37 percent) and engineering and technology (27 percent).

With respect to publication in the more applied journals, growth was observed only in the fields of clinical medicine and physics, 9 percent and 24 percent respectively. These divergent trends among fields may reflect changes in editorial policies or the changing patterns of national support for research among these fields.

There is evidence of considerable growth in cooperative research being conducted between U.S. research institutions.[98] In the field of clinical medicine, for example, coauthored articles with at least one writer employed in a university or college increased from 54 percent in 1973 to 61 percent in 1980.[99] Articles written by U.S. college and university authors are coauthored most frequently with researchers employed by the Federal Government in four of the eight fields examined:[100]

Sector most frequently coauthoring with universities	Field
Federal Government	Clinical medicine
	Biomedicine
	Biology
	Earth and space sciences
Industry	Chemistry
	Engineering
	Mathematics
FFRDC's	Physics

These relationships may derive from funding and employment patterns specific to each field.

Many of the publications by university-based scientists and engineers represent the culmination of many years of research, often by entire laboratories of scientists or engineers where advanced graduate training is also carried out. A recent survey of individuals who earned their doctoral degrees in academic year 1969-1970 reveals that substantial contributions to the literature base are also made through the publication of dissertation results. As table 5-7 suggests, on average, about one journal publication resulted per person from findings derived directly from dissertation research and almost one-half were cited by other research publications (see appendix table 5-28), although publication and citation rates vary considerably by field.

In summary, while all U.S.-authored publications declined by 5 percentage points overall between 1973 and 1980, those by U.S. college and university authors held up quite well, decreasing by only 1 percent in that period. U.S. college and university authors were coauthoring more in

[98]In order to be counted as a "cooperative" effort, an article must be coauthored by at least one author from another organization. An effort has not been made to restrict the analysis only to authors from other sectors. Hence, an article will be counted as "coauthored" if a scientist in one university coauthors an article with a scientist from another university despite the fact that both are employed in the same sector of the labor force.

[99]See appendix table 5-27.

[100]This analysis considers the sector most frequently identified other than coauthorship with other academic authors. See ref. 80.

Table 5-7. Publication patterns of dissertation research for selected fields

Field	Percent publishing	Average number of publications	Percent of publications cited by other publications
Total	50	0.9	47
Biochemistry	71	1.5	51
Zoology	62	1.4	41
Physics	60	.9	49
Electrical engineering	43	.7	30
Psychology	28	.4	72
Sociology	27	.6	58

NOTE: These data are based on publication counts through 1978 for 1,200 individuals who earned their S/E doctoral degrees in 1969/70.

See appendix table 5-28.

Science Indicators—1982

1980 with other sectors, compared to 1973. In four of the eight fields examined, academic researchers coauthored most actively with scientists and engineers working in the Federal sector.

OVERVIEW

Significant changes have come about in recent years in both the scope and magnitude of the U.S. academic science and engineering enterprise, following two decades of almost unprecedented expansion.

National support for academic research and development activities in 1983, for example, is expected to be about 3 percent lower in constant-dollar terms than the historically high level of funding support reached in 1981. The 12-percent average annual constant-dollar growth rate in academic R&D observed in the 1960's slowed to 2.8 percent in the 1970's and is estimated to have remained essentially constant since 1980. At the same time, a significant shift has been reported in the relative emphasis placed on basic research and on applied research and development by our Nation's colleges and universities. Academic expenditures for applied research and development (nearly all of which are in the applied research area) are reported to have grown at an average annual constant-dollar rate of 7.6 percent between 1972 and 1981, six times the rate observed for basic research support. Basic research has thus declined as a proportion of academic R&D expenditures from a level of three-fourths in 1972 to a little over two-thirds of the total in 1981.

S/E degree production is another area in which substantial growth rate changes have already taken place. The number of S/E degrees awarded each year grew rapidly in the 1960's, declined abruptly in the early 1970's, and stabilized later in the decade. At the baccalaureate degree level, for example, 1981 total S/E degree production matched 1975 levels, but still was 3 percent lower than the alltime high reached in 1974. The most significant gains in baccalaureate degree production continue to occur, however, in only two fields of S/E—the computer sciences and engineering which are at record alltime high levels—with slower rates of growth or decline typifying degree production in other S/E fields.

Patterns of academic S/E employment also began to change in the 1970's. These new employment configurations have resulted in changes in the type of academic appointments available to scientists and engineers. Between 1973 and 1981, the number of doctoral S/E's employed in academia increased. Much of this growth was in nonfaculty positions. For example, nonfaculty S/E positions (excluding postdoctoral appointments) grew at an average annual rate of 7.8 percent compared to an average annual growth rate of 1.4 percent in faculty positions. The slower growth in the number of faculty staff has also resulted in a decline in the proportion of young faculty in S/E departments. The proportion of those Ph.D.-holders in full-time faculty positions in doctorate-granting institutions who earned their degrees within the preceding 7 years declined sharply from 39 percent in 1968 to 28 percent in 1974 to 21 percent in 1980.

Academic employment opportunities vary, of course, across fields of science and engineering. About one-tenth of the full-time engineering faculty positions were vacant at the beginning of the 1981-82 academic year. About 9 in 10 engineering colleges reported a decrease in their ability to staff full-time positions during the past 5 years, attributing much of the problem to reduced numbers of new engineering doctoral graduates and increased salary competition from industry in hiring them. Moreover, instructional needs have risen dramatically in this field in recent years, with full-time undergraduate engineering enrollments growing at an average annual rate of over 9 percent between 1977 and 1981.

The slower growth in national support for academic R&D which began in the 1970's has been accompanied by a slowing in the growth of R&D as a primary work activity among academic scientists and engineers. Between 1979 and 1981, the growth of those primarily engaged in R&D increased at a rate of less than 2 percent per year, following a six-year period in which the growth rate averaged 8 percent per year.

There is concern that academic scientists and engineers may not have at their disposal sufficiently up-to-date scientific equipment. Universities and colleges spent 6 percent of all separately budgeted R&D expenditures in 1980 on the purchase of research equipment. However, a preliminary study of selected fields in 38 leading academic R&D institutions has shown that almost 50 percent of the instruments in the laboratories surveyed were less than 5 years old in 1981, while more than 25 percent were more than 10 years old. Evidence also points to a probable relationship between the proportion of equipment unavailable for use because of maintenance or repair work and the average number of users of the equipment.

Academic science and engineering continues to contribute significantly to knowledge production through research publications. U.S. academic authors provide about two-thirds of the research literature appearing in the world's most influential science and technology journals, a ratio that has increased only slightly over the past 10 years. The 10 U.S. academic institutions publishing the most research articles within each S/E field typically account for more than one-fifth of these academic-based publications. There is evidence, furthermore, of considerable growth in cooperative research being conducted between U.S. research institutions. Coauthored articles with at least one writer employed by a U.S. university or college increased from 39 percent in 1973 to 48 percent in 1980. In four of the eight fields examined, U.S. academic authors most frequently coauthored with researchers employed by the Federal Government.

In addition to the generation of new knowledge through research and publishing activities, academic scientists and engineers contribute to the transfer of new technology to the public sector through the patenting of inventions. The number of academic institutions to which patents were issued increased by a factor of two between 1969 and 1980.

The overall picture that emerges, then, for the late 1970's and early 1980's is one of continued, though slower, growth in academic science and engineering.

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Chapter 6
Public Attitudes Toward Science and Technology

Public Attitudes Toward Science and Technology

HIGHLIGHTS

- The public continues to hold scientific research in relatively high esteem. A 1981 public opinion survey found that 7 out of 10 Americans believe the benefits of scientific research outweigh any harmful results. Equally high esteem for science was expressed in 1979. However, the proportion who believe harmful effects outweigh benefits rose slightly. The attentive public—the 20-percent segment of the public that is most interested in and most informed about science and technology—holds still more favorable opinions. Ninety percent of all attentives believe the benefits of scientific research outweigh the harmful results. (See p. 146.)

- However, the public shows some ambivalence in response to questions that link science with technology. For example, three-quarters of the general public believe that most problems can be solved by applying more and better technology. Yet three-quarters also believe that science and technology "often get out of hand, threatening society instead of serving it." (See p. 146.)

- The attentive public has high expectations for scientific advances over the next 25 years. Strong majorities (from 59 to 74 percent) believe that research will lead to new sources of cheap energy, a more economical method of desalinating sea water, a way of predicting earthquakes, and a cure for common forms of cancer. However, they are doubtful about science producing a way to cure inflation or unemployment or a way to put communities of people in outer space. These beliefs are not expert predictions of future developments, but they indicate the areas in which the respondents have more or less confidence in science and technology. (See p. 155.)

- Opinion leaders in science and technology policy outside the Government express some concern about the status of U.S. science and technology in the world. Only 2 in 10 of the opinion leaders believe the United States is currently ahead of other countries in "almost all" areas of basic research, while 5 out of 10 think it ought to be. One in ten thinks this country leads in almost all areas of applied science and technology, while 4 in 10 think it should. (See p. 148.)

- In the context of spending for 11 pressing national concerns, such as crime, health care, and national defense, "conducting scientific research" is ranked seventh by the attentive public. However, half the attentives want increased spending for scientific research. The rest of the public rank this item ninth out of eleven. Nonetheless, very few in either group want to lower current levels of scientific research expenditures. (See pp. 151-152.)

- In choosing among specific research areas for increased funding, 82 percent of attentives mention disease-specific medical research, the area most often chosen. Next in order of mention is research into human learning processes (67 percent). The nongovernment S/T opinion leaders do not share this emphasis on medical research, but identify science and engineering education and basic biological research as their main priorities. (See p. 152.)

- In evaluating specific technologies, the public wants to see continued technological advances in a wide variety of areas, with more than 80 percent favoring further advances in medicine. In 1981, support for advances in nuclear power and synthetic fibers was somewhat lower than in earlier years, while support for space exploration and advanced weaponry was higher. (See p. 155.)

- A majority of the nongovernmental S/T opinion leaders and the attentives agree that the benefits of recombinant DNA research and of nuclear power outweigh the risks, and that the space program is worth the costs. A third of the opinion leaders believe that the level of Government regulation of the construction of nuclear power plants is too low, while a fourth think it is too high. In other cases, a majority considers the level of regulation "about right." (See pp. 156-159.)

- On some subjects—in particular, research that might lead to the creation of new forms of life or the ability to select the sex of a child at conception—about one-half of the attentives are willing to see scientific inquiry restrained. On three other subjects—research that might enable most people to live to be 100 years old, research that might discover intelligent beings in outer space, and research that might lead to precise weather control and modification—no more than one-fifth to one-quarter of attentives want any limits placed on scientific study. (See pp. 150-151.)

- A substantial segment of the general public (38 percent) are "very interested" in new scientific discoveries, and 34 percent are very interested in the use of new inventions and technologies, ranking them fourth and sixth respectively out of nine issue areas. However, people see themselves as having a much lower level of knowledge than of interest in these issues; 13 percent think they are "very knowledgeable" about scientific discoveries, and 11 percent consider themselves very knowledgeable about new inventions and technologies. (See pp. 159-160.)

In September 1945, 3 weeks after the end of World War II, President Truman told a joint session of the Congress: "Progress in scientific research and development is an indispensable condition to the future welfare and security of the nation."

Today, nearly four decades later, science and technology seem firmly imbedded in the Nation's customs and laws. About half the bills introduced in Congress involve science or technology to some degree;[1] the U.S. House of Representatives has a standing Committee on Science and Technology; the President has a Science Adviser and an Office of Science and Technology Policy in the White House; and the Congress has its Office of Technology Assessment. Moreover, some $77 billion per year, equally divided between Federal and private sectors, is being spent on research and development. This amounts to about $350 per year per citizen.[2]

In a democracy, a continued national commitment to scientific research and development must rest firmly upon citizen support.[3] This support is seldom expressed directly. Only rarely does a scientific or technological issue come up for a direct vote by citizens, or even figure prominently in the election of candidates. (Among the rare exceptions are nuclear power and fluoridation.) It is evident, nonetheless, that public financing of scientific activities depends on a tacit consensus that science and technology are vital to the well-being of the Nation. In addition, citizens can use their power to reverse policy decisions on specific issues related to science and technology if they care enough about the issue to mobilize.

In this context, it is especially useful to be aware of public attitudes on science and technology. Public opinion surveys offer a unique way of revealing these attitudes. Through scientific sampling, attitude surveys can represent the views of the entire country. With thoughtful wording of questions, such surveys can bring to public attention views that may not yet have been publicly expressed.

By the same token, since the wording and context of questions is crucial, surveys can be misused.[4] An accurate and sensitive reflection of public opinion depends upon using a wide range of questions to put the issue at hand in perspective, using a variety of questions on a single topic, framing questions that force choices or trade-offs, and comparing answers to the same question over time to capture trends. In spite of these problems, well designed surveys have been shown to give results that apply to the whole population, and are useful for policy studies.[5]

This chapter reports on current views of the U.S. public on several science and technology issues, drawn mostly from surveys done by nationally recognized polling organizations between 1979 and 1982. Attention is given to the views of three special groups, in addition to the views of the broad public. All were surveyed in late 1981.[6] The first special group is the "attentive public"—those citizens, comprising 20 percent of the general public, who take an active, continuing interest in science and technology and keep informed about the issues.[7] People were classified as attentive if they reported a high interest in science or technology, if they achieved a minimum score (based partly on self-ratings) on a simple scale of scientific knowledge, and if they regularly kept up with news of science and technology or with the news in general. In controversial matters, attentives are more likely to take public positions. The second special group, the "potential attentives"—roughly 20 percent of the public—is made up of those who were "very interested" in science and technology but did not achieve the minimum score on the knowledge and information acquisition scales. These people are important in this context because they are the ones who could most readily become attentives.[8] The remainder of the public, by contrast, may recognize the importance of science and technology, but in an era of information overload do not select this area for sustained interest.[9]

The third special group whose views are assessed in this chapter are 287 nongovernment policy leaders in science and technology.[10] The 1981 survey was the first time these people had been identified and systematically surveyed.[11] They were sampled from a specially drawn list of about 3,500 eminent scientists, engineers, doctors, science journalists, and other professional leaders in science-related areas from universities, nonprofit institutions, and industry. Included in the list were all current officers of national scientific societies, recent members of major advisory committees for the Federal Government, officers and board members of the top 20 science and engineering corporations of the Fortune 500 list, members of the National

[1]See ref. 1.

[2]See ref. 2.

[3]See ref. 3.

[4]Methodological studies of these aspects of survey research are still relatively few in number. The most systematic inquiry into question wording effects, using an experimental approach, is ref. 6.

[5]For a general overview of survey research methodology, see ref. 4. A book that critically assesses the use of polls on public policy issues is ref. 5. On the validity of surveys, see also ref. 43.

[6]Telephone interviews were conducted by the Public Opinion Laboratory at Northern Illinois University during November and December 1981. The study of attentives, potential attentives, and the rest of the public is based on a multi-stage cluster sample and a random digit dialing procedure based on a sample of working telephone numbers for each of the 150 primary sampling units. This study follows a major survey of public attitudes toward science and technology conducted in 1979. See refs. 7, 8, and 35.

[7]The attentive public sample that was interviewed in the 1981 survey numbers 637 people. They come from a national sample of 3,195 adults over 18 years of age. The notion of attentiveness was first developed in connection with public involvement with foreign policy. See ref. 34. The characteristics that accompany being attentive are discussed in ref. 36.

[8]Typically, potential attentives' views lie between those of attentives and those of the remainder of the public, who make up 61 percent of the sample.

[9]The analytic report for the study of attentives and potential attentives is ref. 7, which contains copies of the questionnaires used in this study in addition to presenting the basic findings. With the size of the samples for the attentives and potential attentives, reported percentages will differ by 5 points or less from the percentages that would have been reported if the whole group had been interviewed. Where data are reported for the entire general public sample of 3,195, the difference is 3 percentage points or less. For subsamples such as the group with college degrees, the difference would be higher.

[10]With this size of sample, the sampling error of the reported percentages is approximately 7 percentage points or less, although the error will be higher for subsamples. The analytic report for the nongovernmental leaders is ref. 8.

[11]See ref. 8, Section III.

Academies of Science and Engineering, winners of Nobel Prizes for science, and authors of recent books or refereed journal articles on science and technology policy.[12] The reason for selecting the nongovernment leaders for special attention is that they are the most knowledgeable and influential members of the public with regard to science and technology issues. Nongovernment leaders often communicate directly with the policymakers who make decisions on these issues. The policymakers themselves are often drawn from the ranks of the nongovernment leaders.

This chapter describes the attitudes of attentives, potential attentives, and nongovernment leaders, as well as those of the general public, on the broad issues. It also gives in some detail the preferences of the leaders, potential attentives, and attentives for various scientific endeavors, as well as their opinions on certain highly visible issues: recombinant DNA, nuclear power, space exploration, and government regulation of science and technology. In some cases, parallel data on these topics from other national surveys are introduced for comparison. Finally, the chapter points out similarities and divergences between the attentives, the potential attentives, the general public, and the nongovernment leaders.

GENERAL ATTITUDES TOWARD SCIENCE AND TECHNOLOGY

Overall Benefit vs. Harm

The public continues to hold scientific research in relatively high esteem. In the 1981 survey, about 7 out of 10 adult Americans said that the benefits of scientific research have outweighed the harmful results.[13] This level of support is similar to that in a 1979 national survey of public attitudes toward science and technology (table 6-1 and appendix table 6-2). The opinion of the attentive public is even more favorable, with high percentages of attentives and of potential attentives concluding that scientific research has produced more benefit than harm. However, the number holding the opposite view has increased slightly since the question was asked in 1979.[14]

A certain ambivalence in public opinion appears, particularly in response to questions that join technology with science (table 6-2). According to a 1982 poll, people are strongly optimistic that science and technology can raise America's standard of living and solve problems (items a and b of table 6-2). This optimism is tempered: a majority does not believe that scientists could solve any problem we might face (item c). A less positive public sentiment also emerged from this poll when people were asked whether science and technology do as much harm as good. A majority said yes (item e). When the issue was posed as "science and technology often get out of hand, threatening society instead of serving it," more than three-quarters of the respondents agreed (item b).[15]

Some indication that public opinion is more favorable toward scientific knowledge than toward its technological results appears in the survey of the attentive public.[16]

[12]The demographic composition of the attentive, potential attentive, and nongovernment leadership groups can be seen on appendix table 6-1.

[13]This level of support was also found by surveys discussed in ref. 41.

[14]Questions about the balance between the good and bad effects of science and technology have been asked in surveys since 1957. For summary, see ref. 9, p. 161.

[15]The response to agree/disagree questions of this type is known to be particularly sensitive to variations in question wording. Thus, here and elsewhere, the meaning of the exact percentages reported is not always clear. However, the responses taken together suffice to bring out the ambivalence in the public's feelings about science and technology.

[16]For other studies which made similar observations, see ref. 10 and ref. 11.

Table 6-1. Beneficial versus harmful consequences of scientific research: 1981
(Percent)

Response	Total public	Attentives	Potential attentives	Rest of public
Benefits have outweighed harms	74	90	79	66
About equal[1]	11	3	5	15
Harms have outweighed benefits	14	7	15	18
Don't know	1	—	1	2
N =	1,540	637	617	924

"Now, for a different type of question. People have frequently noted that scientific research has produced both beneficial and harmful consequences. Would you say that, on balance, the benefits of scientific research have outweighed the harmful results, or have the harmful results of scientific research been greater than its benefits?"

[1] Interviewers accepted "about equal" as a response, but did not suggest it.

NOTE: N's do not add because of oversampling of the attentives and potential attentives.

SOURCE: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 11, and Jon D. Miller, unpublished data.

Science Indicators—1982

Table 6-2. The general public's views about science and technology: 1982
(Percent)

Question	Agree	Disagree	Don't know
d. "Through science and technology we can continue to raise our standard of living."	80	18	3
a. "Most problems can be solved by applying more and better technology."	77	21	2
c. "Scientists can solve any problem we might face if they are given enough time and money."	42	55	3
e. "Science and technology do as much harm as good."	56	39	4
b. "Science and technology often get out of hand, threatening society instead of serving it."	77	21	2
N = 1,310			

NOTE: The questions were asked in the indicated order, from a to e.

SOURCE: Research and Forecasts, Inc., survey performed for The Continental Group, Inc., unpublished data.

Science Indicators—1982

Both attentives and potential attentives agree, by very large margins (88 percent and 86 percent respectively), that scientific knowledge "is good in itself: it is only the way it is put into practice that often causes problems."[17] A substantial majority of the attentives is doubtful about a technological safety net for potential harm from technological development; 61 percent disagree with the strong statement that "new inventions will always be found to counteract" any such harmful consequences.[18] The potential attentives are more optimistic that technological fixes will be found; 53 percent agree with the statement.

Status of U.S. Science and Technology in the World

Surveys have shown that the public regards "technological know-how," "scientific creativity," "scientific research," and "industrial know-how" as the most important in a long list of factors which have given the United States a leading influence in the world.[19] Recent data show that the public harbors some doubt about the continued primacy of American technology, especially with regard to Japan. The survey of nongovernment leaders indicates that they share some of these doubts.

A May 1981 survey asked whether "U.S. technology and know-how" are better than, equal to, or not as good as the technology of four other major industrial nations: France, West Germany, the Soviet Union, and Japan (table 6-3). While U.S. technology was clearly rated higher in the case of the first three countries, the ratings were more nearly even when the United States was compared with Japan.[20] Of the scientists, engineers, and administrators

[17]See ref. 7, table 12.

[18]See ref. 7, table 13.

[19]See ref. 9, p. 164.

[20]According to the Sentry study of productivity, given a choice of four factors, 49 percent of a sample of U.S. business executives chose "a failure to invest enough in new equipment and facilities" as the factor which has done most "to inhibit the growth of productivity in this country." Only 23 percent of Japanese executives in a parallel study chose this factor. See ref. 15, p. 74.

Table 6-3. General public's comparison of U.S. technology with technology of selected countries: 1981
(Percent)

Country	Better than	Equal to	Not as good as	Don't know
France	70	16	4	10
West Germany	45	34	12	9
The Soviet Union	45	32	17	6
Japan	37	37	22	4
N = 1250				

"Do you feel that U.S. technology and know-how today is better than, equal to, or not as good as the technology of . . ." (Each country was read by interviewer.)

SOURCE: The Harris Survey, #43 release (May 28, 1981).

Science Indicators—1982

Table 6-4. Leaders' view of the international position of the U.S. in basic and applied research: 1981
(Percent)

	Basic research	Applied research[1]
U.S. is currently ahead of other countries in:		
Almost all areas	19	9
Most areas	59	57
Only a few areas	17	31
Don't know	4	3
U.S. should be leader in almost all areas:	50	38
N = 287		

"Now let me ask you to compare American science and technology to that of other countries. First, in terms of basic scientific research (applied science and technology), would you say that the United States is currently ahead of other countries in almost all areas . . . *in most areas* . . . or in only a few areas of basic scientific research (applied science and technology)?"

"As a matter of national policy, do you think the United States should seek to be the leader in almost all areas of basic scientific research (applied science and technology), or should we focus our efforts on only selected areas of basic research (applied science and technology)?"

[1] Includes technology.

See appendix table 6-3.

Science Indicators—1982

surveyed in the 1981 study of leaders, only one in five considers the United States ahead of other countries in "almost all" areas of basic research (table 6-4). With regard to applied science and technology, fewer than 1 in 10 see this country as ahead of others in "almost all" areas. In the case of both basic research and applied science, the majority of respondents takes the middle position that the United States is ahead in "most" areas. However, nearly one leader in three holds the pessimistic view that with regard to applied science, the United States is ahead in "only a few" areas.

The leaders express considerable dissatisfaction with the state of affairs as they see it. Half think the United States should lead in "almost all" areas of basic research—more than twice as many as those who believe the United States does in fact lead. Various disciplines differ, however. Biological and physical science leaders are the strongest proponents of U.S. supremacy in basic research. The majority of social scientists and engineer/medical scientists[21] chose the alternative position offered in the question, that the United States should focus national efforts on only selected areas of basic research (appendix table 6-3). Support for U.S. supremacy in applied science and technology is less strong. Nevertheless, about 4 out of 10 leaders think this Nation should be ahead in "almost all" areas, compared with the 1 in 10 who believes this is now the case.

[21]Because of the small number of leaders in the engineering category, they were combined with other groups of applied scientists, the largest number of whom are medical scientists and administrators. See ref. 16.

An important foundation for world leadership in science and technology is a strong system of education in science and engineering. Although 89 percent of the nongovernment leaders believe that the United States ought to be the world leader in this area, only 58 percent believe that it actually is. At the same time, the leaders show concern about the current quality of precollege science education. When asked whether "the quality of science instruction in American high schools is on the rise," 63 percent disagrees, 21 percent strongly.[22] The attentive public is somewhat more sanguine about the status of science instruction than the leaders; only 46 percent disagreed when asked the same question.[23] As a later section of this chapter shows, the leaders questioned in the survey gave high priority to funding for science and engineering education.

The foregoing results suggest that the American public has a relatively high regard for science and technology. The more awareness people have of science and technology issues, the greater their support. While public esteem for science appears strong and clear, technology seems to evoke a more complicated response. Americans appreciate technology for its contributions to the Nation's high standard of living, but many are concerned that some applications of science may get out of hand, threatening society with dangerous, unintended consequences. Nongovernment leaders of science policy express some concern about U.S. world leadership in science and technology and believe that it should be improved as a matter of national policy.

Confidence

Some writers on the role of science in American society believe they discern a growing distrust of science as it affects the well-being of society.[24] Confidence in science has fallen in the last two decades, they say, as controversy over certain scientific and technological issues has become more common, and as the side effects of technological advances (such as air pollution caused by automobiles) are better understood by the public. This view seems to be accepted by the 45 percent of the nongovernment leaders who agreed with the statement that "there is a growing distrust of science in the United States today."[25] Among the various disciplines, biological scientists most often agreed with the statement (61 percent)—perhaps because of recent controversies over recombinant DNA and genetic engineering. As described below, the leaders in general put "inadequate public understanding of science" near the top among problems on the Nation's science policy agenda.

To assess whether there is in fact growing distrust of science, it is useful to review survey findings on public confidence in the leadership of various institutions. Such polls often include "medicine" and the "scientific community" in their list of institutions. Relevant questions

[22]See ref. 8, table 22, 48.
[23]See ref. 7, table 18.
[24]See ref. 12 for a brief review of this literature.
[25]See ref. 8, table 18. This view was shared by 43 percent of attentives and 51 percent of potential attentives. See ref. 7, table 18.

are repeated often enough by the same survey organizations that changes over time may be revealed.[26]

These polls show that the leadership of "medicine" and that of "the scientific community" currently stand highest in public confidence of the institutions included in the surveys (table 6-5). This probably reflects the level of public confidence in the medical and scientific communities themselves.[27] As for shifts in confidence over time, polls on the question from 1966 to 1982 do suggest that a slide in public confidence in *all* institutions has taken place over 16 years.[28] Nevertheless, medicine has remained at the top among the listed institutions over this entire period, and science, exhibiting a slight upward trend, is now second. The National Opinion Research Center (NORC) series, which began in 1973, shows that confidence in the scientific community has essentially remained steady throughout the past decade (appendix table 6-4).[29]

The data show that the higher people's educational level, and the more they report that they follow "what's going on in government and public affairs," the more confidence they have in the scientific community.[30] In this respect, the scientific community is unique. No such relationship was found for the 12 other institutions included in the poll (table 6-5). This finding reinforces results from the survey of the attentive public: the more aware people are about science and technology, the more supportive they tend to be of these institutions.[31]

Despite the strong, steady expressions of public confidence in the science community, a more complex picture sometimes emerges in answer to related questions. In a survey that asked the general public to rate institutions on the "trustworthiness of information" they provide, the

[26]Smith has shown that there are only partial explanations for the differences in confidence levels recorded by different survey firms using the same questions at approximately the same time. See ref. 13. The trend data presented here are restricted to polls taken by one survey house, the National Opinion Research Center (NORC). This is intended to minimize (though not completely eliminate) the variability not associated with true attitude change.

[27]Methodological research on the question used in these surveys has shown that "confidence is a widely and correctly understood term" and that "the concepts of trust and faith are central" to people's understanding of the term. A substantial minority (40 percent) were unable to come up with a relevant organization, group of people, or individual when asked whom they have in mind when they think of was was the people running the scientific community. This suggests that their answers to this question represent a generalized response to the image of the scientific community rather than to its leadership. See ref. 13, pp. 119-171.

[28]See ref. 12.

[29]Similar results were found in a survey of the California population in late 1981. See ref. 14. The scientific community receives an especially high level of "don't knows" on table 6-5. This may be due to the low level of public familiarity with science and scientific leaders.

[30]Fifty-two percent of those who follow "most of the time" what is going on in government and public affairs whether there is an election going on or not, possess this degree of confidence, as compared with 43 percent for the sample as a whole. Tabulation provided by Tom Smith, using data from the 1982 General Social Survey conducted by the National Opinion Research Center.

[31]Similar results were found in a national survey in 1957. See ref. 37.

Table 6-5. Confidence of the general public in leaders of major institutions: 1982

(Percent)

Institution	Great deal	Only some	Hardly any	Don't know
g. Medicine	46	46	7	1
j. Scientific community	38	46	6	10
c. Education	33	51	13	2
b. Organized religion	32	49	15	4
i. U.S. Supreme Court	30	53	12	4
l. Military	31	52	15	3
m. Banks and financial institutions	27	55	16	2
a. Major companies	23	58	14	6
f. Press	18	59	21	2
d. Executive branch of the Federal Government	19	54	24	3
h. Television	14	57	27	2
k. Congress	13	62	22	2
e. Organized labor	12	53	30	5
	N = 1,506			

"I am going to name some institutions in this country. As far as the *people running* these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?"

NOTE: The items were asked in the indicated order, from a to m.

SOURCE: *General Social Surveys: 1972–1982* (Chicago: National Opinion Research Center, University of Chicago, 1982), pp. 111–114.

Science Indicators—1982

scientific community received only a medium ranking (appendix table 6-5). The medical community once again was at the top, together with higher education. It should be noted that the confidence question appeared after a series of questions probing public opinion on environmental and energy trade-offs. In this context, the public may have been reacting negatively to the use of scientific justifications for opposite sides of energy and environmental controversies. Nevertheless, about two-thirds of the public in this survey regarded the information they got from the scientific community as trustworthy at least "most of the time" compared to four out of five for the medical community. Moreover, in another question in the same survey, the scientific community was rated highest as a source of information about the risks of nuclear power.[32] In fact, people placed the scientific community well ahead of the opponents of nuclear power, the Government, and the utility companies as a source to be trusted.

Science and Economic Growth

Strongly favorable views toward science appear in the assessment by attentives of another topic that affects people directly: the relationship between science and economic health. Sixty-two percent of the attentives discern a close tie between basic scientific research and economic growth; another 28 percent see a loose tie. Potential attentives are somewhat less convinced, yet 83 percent believe there is some relationship. The attentives' views on this question parallel their strongly favorable views about scientific research in general.[33]

[32]See ref. 42.
[33]See ref. 7, table 6.

In answer to a similar but differently worded question, 34 percent of nongovernment leaders said they believe that the economic growth of a nation is largely determined by its level of basic scientific research, while 60 percent think that economic growth is "only somewhat determined" by basic research. Only 5 percent see no relationship.[34]

Limiting Scientific Inquiry

The question of limiting scientific inquiry is closely allied to public apprehension about possible harm to society from scientific or technological development. Some people have expressed fears that scientists or engineers may be doing studies that should be left alone. On the other hand, scientists might be expected to take the view that interference with the freedom of scientific inquiry is potentially dangerous to scientific progress. In recent years, controversy over limiting scientific inquiry has been especially heated on research with recombinant DNA. How supportive is the most interested and knowledgeable segment of the public toward free inquiry in subjects with dramatic implications for everyday life?

Members of the attentive and potentially attentive public were told in the 1981 survey that "some people are worried that scientists are studying problems that are better left alone" and that others "feel it is a bad idea to limit the kinds of things that scientists can study." These groups were then asked whether scientists should or should not be allowed to conduct certain kinds of research (table 6-6). Only one-fifth to one-fourth of the attentives oppose research aimed at extending human life

[34]See ref. 8, table 11 and ref. 40.

Table 6-6. Willingness to restrain scientific inquiry: 1979 and 1981

	Percent willing to prohibit scientific research concerning . . .					
Respondents	New forms of life	Sex of child at conception	Intelligent life in outer space	Living to be 100+	Controlling weather	N
Attentives, 1979	51	NA	12	20	20	322
Attentives, 1981	50	50	24	20	20	637
Potential attentives, 1981	67	57	27	24	23	617

NA = not available.

"Next, let me ask you about the types of studies that scientists ought to be able to conduct. Some people are worried that scientists are studying problems that should be left alone. Other people feel that it is a bad idea to limit the kinds of things that scientists can study.

I'm going to read you a short list of studies that have caused some debate. For each study, please tell me whether you think scientists should or should not be allowed to conduct that kind of research. If you don't care one way or the other, just give me that answer.

First, studies that might enable most people in society to live to be a hundred or more. Should scientists be allowed to conduct this type of study or not? . . . Studies that might lead to precise weather control and weather modification? . . . Studies that might allow scientists to create new forms of life? . . . Studies that might discover intelligent beings in outer space? . . . Studies that might allow parental selection of the sex of a child at the time of conception?"

See appendix table 6-6.

Science Indicators—1982

to age 100 or more, the discovery of intelligent life in outer space, and "precise" control over the weather. When it comes to research that might give people control over the sex of their child or research "that might allow scientists to create new forms of life" (which, in the context of these questions, may have been interpreted by the sample as potentially creating a monster),[35] fully one-half of the attentive public has misgivings. Only 24 percent of the attentive public is willing to allow scientists to pursue all five of the listed areas of research (see appendix table 6-7). The potential attentives are even more resistant to allowing research on the topics in question. Willingness to restrain scientific inquiry is especially common among those in the oldest age group and can also be noted in the youngest age group, at the lower educational levels, and, in specific areas, among women.[36]

Four of the five questions asked in 1981 were also asked in the 1979 survey. In this brief time interval, there was an apparent change in only one item: in 1979, one in ten of the attentives was willing to restrict research that might discover intelligent beings in outer space; by 1981, this number had risen to nearly one in four.

Table 6-7. Support for increased spending for problems: 1981
(Percent)

Problem area	Attentive public	Potential attentives	Rest of public
Helping older people	77	74	71
Reducing the crime rate	71	81	75
Providing and conserving energy	64	53	45
Improving education	63	60	61
Reducing and controlling pollution	63	55	47
Improving health care	59	62	60
Conducting scientific research	49	35	25
Helping low-income persons	42	45	45
Exploring space	39	24	10
Developing and improving national defense weapons ...	32	43	31
Preventing and treating drug addiction	23	17	14
N =	326	312	1017

"We are faced with many problems in this country. I'm going to name some of these problems, and for each one I'd like you to tell me if you think we're spending too much money on it, too little money on it, or about the right amount."

SOURCE: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 14.

Science Indicators—1982

PUBLIC PREFERENCES AND EXPECTATIONS

Science Versus Other Spending Priorities

However favorably the public may regard scientific research, these activities must still compete with many other desirable programs for funds. The surveys of attentives and leaders asked questions that put spending for scientific research in the context of spending for other goals. Despite the long range character of payoffs to be expected from basic research and the pressing nature of other national needs, the results suggest that the attentive public is sensitive to the funding needs of scientific research. The general public, while by no means antiscience, is somewhat less supportive.

Members of the general public—the attentives, the potential attentives, and the rest of the public—were asked to consider 11 programs supported by Federal funds, and to say whether "we are spending too much, too little, or about the right amount" for each.[37] Except for "conducting scientific research," all programs on the list concern specific social problems. A number of these, such as crime, health care, and national defense, are regarded as pressing national problems.

All three groups place "reducing the crime rate" and "helping older people" at the top of the list[38] (table 6-7); "improving health care" and "improving education" are also strongly favored for increased funding by all three groups. "Conducting scientific research" places seventh among the 11 programs with the attentive public, and ninth with both the potential attentives and the rest of the public. While half of the attentives want increased spending for scientific research, only about one-third of the potential attentives and one-quarter of the rest of the public favor this. Very few say they want lower than current levels of spending for scientific research.

A survey of the general public conducted in November 1981 showed similar results. This survey, examining a different list of programs, also asked whether spending for each was too low, too high, or at the right level. This survey explicitly stated that the spending came from "all sources, government and nongovernment." A follow-up question asked whether people thought a cutback in Government spending in each of the areas would be made up by the private sector (appendix table 6-8).

Again, services for the elderly rank first. "Basic scientific research" occupies a middle position in this list: two out of five people think spending is too low; only 15 percent say it is too high. About half doubt that cutbacks in government aid for basic research would be made up by the private sector.

Reflecting the present atmosphere of budget stringency and the setting of priorities, the surveys of both the attentive public and the nongovernment leaders asked whether basic scientific research should be cut proportionally if

[35]The relevance of this finding to the attentives' views about recombinant DNA research is discussed later in this chapter.

[36]See appendix tables 6-6 and 6-7. Appendix table 6-7 is based on an index that shows the number of research areas on appendix table 6-6 that the respondent wishes to see restricted.

[37]Questions in this form are frequently used in opinion surveys to get a rough measure of the relative priorities the public assigns to each area. The limitation of such questions is that respondents may consider some area to be of high priority but already amply funded.

[38]This ranking is based on those who said the present amount of funding for these areas is "too little."

total Federal spending is cut, or whether spending for this purpose should be exempt from cuts. Only 28 percent of the leaders favor a proportional cut for basic science. In contrast, 69 percent of the attentives and 74 percent of the potential attentives would favor such an approach.[39]

Science Policy Agenda

To the nongovernment leaders, one of the most pressing issues in science and technology policy today is adequate funding for basic scientific research. Asked to comment on seven issues in science and technology and to categorize them as "a major problem," "a problem but not major," or "not really a problem,"[40] fully two-thirds of the leaders cite funding for basic research as a major problem (table 6-8; cf. appendix table 6-9). In all settings and disciplines from universities to industry, from engineers to biologists, the leaders put this issue at the top of their national agenda of major problems.[41]

Ranking next with the nongovernment leaders are public understanding of science and precollege science education. Nearly half cite these as major problems. Among the various disciplinary groups, the biologists are somewhat more concerned about public understanding of science (again, perhaps a reflection of the public debate about recombinant DNA research and genetic engineering), and the physical scientists show a special concern about high school science education.

The two items of least overall concern on the list are incentives for industrial research and development and applying scientific knowledge to end products and uses. Not surprisingly, incentives for industrial research are of greater concern to leaders in the for-profit sector than to others; even so, these leaders, like the rest of the group, are far more interested in funding for basic research than in any other issue.

The leaders showed their serious concern about funding for basic research in their answers to another question as well. Told to assume that the level of Federal funds for scientific research and development will remain constant over the next 5 to 10 years, leaders were asked about their preferences for reallocating resources more toward basic scientific research or more toward applied research. In this no-growth funding situation, almost half of the leaders would favor basic research. Only 13 percent would favor applied research (appendix table 6-10). No disciplinary subgroup among the leaders would favor applied research at the expense of basic research. While leaders from academia—where most basic research is performed—might be expected to favor basic research, it is notable that even among the private industry respondents support for basic research is at least equal to support for applied research.

The attentive public gave quite a different answer to the same question. Fewer than 3 out of 10 of the attentives would favor increased funding for basic research. The remaining 7 out of 10 in about equal numbers would prefer maintaining the present balance or increasing funds for applied research (appendix table 6-10).

The attentives' preference for applied science research emerged in another question as well. Members of the attentive and potential attentive public as well as the nongovernmental leaders were given a list of 12 items, and asked to state their preferences for more funding, less funding, or a constant level. Again, the assumption was that total spending would be held level. In this situation, four out of five attentives and potential attentives would favor increased spending for disease-specific medical research (table 6-9). This item is at the top of their list by a large margin.[42] Only a third of the leaders would support more funding for disease-specific medical research. In the case of basic research in biology, chemistry, and physics, the nongovernment leaders assigned them high priority, especially in the case of biology. Attentives gave them nearly average rankings, while potential attentives gave them relatively low rankings. Economic research was a relatively high priority for attentives and potential attentives (especially the latter), but it was quite a low priority for the leaders.

In other areas, the choices of leaders and attentives were much more alike. Both rank science and engineering education and human learning research among the top three items that deserve increased funding. Both put mathematics and weapons research among the bottom three.

Table 6-8. Major problems for science and technology, identified by non-governmental S&T leaders: 1981

Problem	Percentages classifying each problem as major
Funding for basic scientific research	66
Public understanding of science	48
Pre-collegiate science education	45
Scientific instrumentation for research	31
Training and research opportunities for young scientists	28
Incentives for industrial research and development	22
Applying new scientific knowledge toward end products and uses	19
N = 287	

"Now, let me read you a list of some issues that other people have mentioned, and for each one—as I read it—I'd like for you to indicate if you think it is a major problem, a problem but not major, or not really a problem."

See appendix table 6-9.

Science Indicators—1982

[39]See ref. 40 and ref. 7, table 15.

[40]The list was derived from the literature and consultants' advice. The seven items in it closely matched answers to an open-ended question in the leaders' survey, which asked "what do you think is the most important science policy question facing the United States today?" See ref. 8, appendix B.

[41]The attentive public was not asked to name or rank major problems in science and technology, but answers to other questions in this survey indicated a somewhat lower level of support for basic research and a greater interest in applied science or utilitarian programs.

[42]A similar preference for applied research, especially health oriented, is shown in a 1981 survey of the Canadian public. See ref. 17, p. 77. The priorities of the European public are discussed in ref. 43, p. 60.

Table 6-9. Areas of science for increased funding if total Federal support were to be held constant: 1981

Area	Percent approving increases		
	Science policy leaders	Attentives	Potential attentives
l. Science and engineering education	55	57	52
a. Basic biological research	54	44	35
h. Human learning process research	42	67	67
i. Basic chemistry research	41	47	49
k. Engineering research	39	46	46
c. Basic physics research	37	46	37
f. Behavior in complex organizations research	33	39	40
j. Disease specific medical research	34	82	84
d. Space exploration	34	47	38
e. Mathematics research	22	32	32
b. Economic research	18	48	53
g. Weapons research and development	11	36	47
N =	287	637	617

"In the context of a no-growth federal resource situation, some people have suggested a reallocation among various areas of science to recognize differences in need and probable outcomes. I'd like to read you a short list of areas of scientific research currently receiving federal support and I'd like for you to indicate if you would prefer *to increase, to decrease*, or *to hold constant* the share of federal funding for each area. In the same context, would you prefer to increase, to decrease, or to hold constant the share of federal funding for science and engineering education?"

NOTE: The items were asked in the indicated order, from a to l.

SOURCES: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb: Ill.: Northern Illinois University, 1982) table 17; Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 13–17, 23, 27–32.

Science Indicators—1982

Table 6-10. Views about policies to promote technological innovation by American industry: 1981
(Percent)

Policy	Respondents	Agree	Disagree	Don't know	N
American industry should invest more heavily in scientific research and development	Leaders	93	5	2	287
	Attentives	91	8	1	637
	Potential attentives	88	11	1	617
The Federal Government should provide larger tax incentives to increase industrial research and development	Leaders	70	26	3	287
	Attentives	72	27	1	637
	Potential attentives	70	29	1	617
If patent laws in the U.S. were modified to extend the period of exclusive use, we would see a major increase in technological innovation	Leaders	25	66	10	287
	Attentives	58	37	5	637
	Potential attentives	69	25	6	617

See appendix table 6-12.

Science Indicators—1982

(The potential attentives, however, give a higher ranking to weapons research, placing it around the middle of the list.)

Government and Industry Roles in Fostering Research

Another way of looking at the question of government spending for research is to ask people how large a role they think government should undertake in this area. Closely connected is the question of how active a role industry should take in promoting research and innovation. Recent surveys indicate widespread public support for a government role in basic research and a conviction that industry should invest more heavily in scientific research.

A 1981 public attitude survey asked how much government should be involved in "fostering basic research" in the context of eight other areas "in which government might play a role." Of the nine areas, four—good health care, protection of the environment, economic development, and provision of enough good jobs—received considerably stronger support than basic research for a "major government role" (appendix table 6-11). However, 89 percent of the people surveyed favor some degree of government involvement in basic research with more than half saying government should play a "major role."

According to the 1981 surveys, nongovernment leaders, the attentive public, and potential attentives all agree overwhelmingly that American industry should invest more in scientific research and development (table 6-10). The three groups also support, by large margins, larger Federal tax incentives for industrial research and development. Interestingly, the leaders and the attentive public disagree on changing the patent laws to allow a longer period of exclusive use. A majority of attentives and a larger majority of

Table 6-11. General public's preferences for advances in technology: 1974, 1976, and 1981

		Percent desiring continued advances		
	Field of technology	1974	1976	1981
e.	Medical transplants (heart, kidney, etc.)	88	89	90
f.	Biological and medical engineering to improve or correct defects in human beings	NA	NA	82
k.	Development of new food sources	83	76	76
g.	Methods of local public transportation (buses, subways, etc.)	85	77	75
d.	Nuclear power for peaceful purposes	70	70	59
a.	Exploration of space	42	49	57
c.	Cable TV technology, programming, and home information services	NA	NA	54
h.	Synthetic fibers and materials (nylon, dacron, etc.)	67	65	54
b.	Advanced weaponry (missiles, etc.)	40	45	50
j.	Compact computers for home use	NA	NA	48
l.	Automated and self-service shopping facilities (self-service food markets, gas stations, automated banking, etc.)	40	39	39
i.	Synthetic foods (meat substitutes made from soy protein, chemicals, etc.)	34	36	35
(j.)	Development of new living spaces (under sea, in space)	46	45	NA
(f.)	Speed of jet planes for long distance travel	31	29	NA
(c.)	Electronic surveillance devices (microphones, wire taps, etc.)	24	27	NA

NA = not available.

NOTE: The items were asked in the indicated order, from a to l. Three substitutions were made in the 1981 survey.

See appendix table 6-13.

Science Indicators—1982

potential attentives agree with the suggestion that this change would bring forth a major increase in technological innovation. Two-thirds of the leaders disagree, and there is also a relatively high percentage reporting "no opinion." The negative assessment of the usefulness of extending the duration of patent protection was shared by all subgroups of the leaders, including the engineer/medical scientists and those in the for-profit sector.

Desirable Advances in Technology

People's personal assessments of the specific goods and services provided by applied scientific research and technology are bound to have a good deal of weight in their overall assessment of the benefits and harm of science or technology, in their preferences for further scientific and technological advances, and in their willingness to spend society's resources (both public and private) to get them. Three times over the past decade, members of the public have been asked whether they believe that certain technologies should be advanced further or whether they think that the technologies have already gone too far. The results suggest that, for the most part, Americans continue to desire technological advance (table 6-11). More than 8 out of 10 surveyed said they desire further advances in two medical technologies. Large majorities also favor further development of new food sources and public transportation. Although slightly less than half of the public look forward to continued advances in home computers, 64 percent of the college educated public said in 1981 that they favor further progress in this field. In 1981, a majority also wanted continued advances in nuclear power, a particularly controversial technology, although support was somewhat lower than in 1974 and 1976. Support for advanced weaponry increased from 1974 to 1981. Space exploration rose in the public estimation so that in 1981 a majority favored continued advances in the exploration of space, as compared with a minority in earlier years.

The generally very favorable public responses to these lists of specific technologies contrast with the sense of some uneasiness about scientific and technological advance discussed above. It appears that people are inclined to evaluate technological advance favorably in areas with which they are familiar. Medical advances have a particularly strong appeal.

Expected Advances in Science and Technology

Consistent with their high esteem for science and technology and their support for continued funding of scientific research, large majorities of attentives and potential attentives have high expectations of scientific advance over the next 25 years (table 6-12). At least three out of five in both groups think it "very likely" that, within a quarter of a century, scientific research will come up with a more efficient source of cheap energy, an economical way to desalinate salt water, a way to predict earthquakes, and a cure for common forms of cancer. These groups are not so sanguine about finding ways to control inflation and unemployment or to put communities in outer space. Only one-fifth of attentives and roughly one-quarter of potential attentives expect success in these last two areas. Attentives and potential attentives have very similar opinions, except that attentives are more optimistic about the most favored achievement (energy) and more pessimistic about the least favored achievements (inflation, unemployment, outer space). In general, the attentives and potential attentives are not technical experts in these subjects and are not necessarily in a position to make accurate forecasts of technical developments. However, their responses indicate their level of confidence in science in specific areas of application.

Table 6-12. Expectations that possible scientific achievements are very likely within 25 years: 1979 and 1981
(Percent)

Achievement	Attentives		Potential attentives	
	1979	1981	1979	1981
Cheap energy	81	74	59	65
Predict earthquakes	72	63	54	62
Desalinate salt water economically	64	62	45	63
Cancer cure	58	59	48	61
Put communities in outer space	28	21	17	23
Control inflation and unemployment	NA	19	NA	28
N =	322	637	335	617

NA = not available.

"Now, let me ask you to think about the long-term future. I am going to read you a list of possible scientific results and ask you how likely you think it is that each of these results will be achieved in the next 25 years or so. a.) A way to predict when and where earthquakes will occur. Do you think that it is very likely, possible but not too likely, or not likely at all that researchers will achieve this result within the next 25 years or so? b.) More efficient sources of cheap energy. c.) A cure for common forms of cancer. d.) A way to put communities in outer space. e.) A way to economically desalinate sea water for human consumption. f.) An economic theory to control inflation and reduce unemployment."

See appendix table 6-14.

Science Indicators—1982

Table 6-12 suggests that there was a slight overall decline from 1979 to 1981 in the attentive public's expectations from science and a comparable increase in the expectations of the potential attentives.[43] In the 1981 survey, the views of men and women, young and old, and the more or less educated are similar on these questions (appendix table 6-14). Young people, for example, are no more confident than their elders that important scientific advances will take place in the next 25 years.

The attentives' optimism about new energy sources is shared by nongovernment leaders. About 83 percent of the leaders and a similar proportion of attentives and potential attentives believe that science and technology can be depended upon "for a long term solution to the energy problem" (appendix table 6-15).

[43]The 1979 survey was the first to identify attentives using the methodology later employed in the 1981 survey. Although the earlier study was conducted using in person interviews, its findings are comparable with those of the 1981 telephone study. See ref. 18.

In sum, survey results indicate that in comparing scientific research with other national funding needs, science appears to have considerable support, especially among attentives. It is by no means at the top of the list, but half of the attentives favor increased funding for scientific research. Few among the general public wish to cut back spending for this purpose.

Nongovernment science policy leaders are strongly supportive of basic scientific research, rating adequate funding for this purpose as a high priority for national science policy. Attentives are more inclined to favor applied science or utilitarian programs, such as disease-specific medical research. The importance of science and engineering education and of human learning process research appeals to both leaders and the attentive public. The surveys indicate that the public desires continued technological advance in most areas, especially in health care, and has high expectations of such progress in developing desalinated seawater, predicting earthquakes, developing new sources of energy, and finding cures for cancer.

SPECIFIC ISSUES

Some scientific and technological issues receive so much attention, or generate so much controvery, that the general public becomes actively interested and sometimes politically involved in them. Other issues, no less important, receive less publicity, and a narrower segment of the public gives them much consideration. In the 1981 survey, the views of the attentive public, the potential attentives, and the nongovernment leaders were explored on selected issues. These included nuclear power, a highly visible and highly controversial subject; recombinant DNA, also controversial but not a front page news item; Federal regulation of various aspects of science and technology; and space exploration, a subject of renewed publicity and interest with the launching of the space shuttle.

Recombinant DNA

When research on recombinant DNA, or genetic engineering, was first widely discussed, many scientists and concerned citizens expressed fears that the new technology might be abused, or might accidentally liberate harmful new forms of life.[44] In 1976, an advisory committee established by the National Institutes of Health (NIH) issued guidelines intended to regulate all NIH-funded research on recombinant DNA, and to set a standard for research in industry, universities, and elsewhere. As experience with the new technology grew, many research projects were exempted from the guidelines' controls.[45] In 1982, the NIH Advisory Committee recommended new guidelines, dropping some restrictions but keeping some controls and prohibitions.[46]

Most of the debate over recombinant DNA has taken place among scientists and policy leaders, although the issue has also been widely discussed in the media with at least some segments of the public closely interested in it. The 1981 survey of nongovernment science policy leaders reflects the evolving consensus among scientists that recombinant DNA research is a legitimate and highly promising enterprise. A very large majority (76 percent) of the leaders surveyed says that the benefits outweigh the risks (appendix table 6-16). Among biologists, who in general are closest to this controversy, 89 percent say that the benefits outweigh the risks.[47] Among the attentive public, support is also strong; 58 percent assess the benefits as greater than the risks, while 32 percent hold the opposite view. A plurality of 47 percent of the potential attentives also believes that benefits outweigh risks; risks appear greater than benefits to about 35 percent.

As discussed above, one-half of the attentives and two-thirds of the potential attentives believe that scientists should not be allowed to conduct research that might allow them to create new forms of life, a position in apparent contradiction with this favorable assessment of recombinant DNA research (cf. appendix table 6-6). What underlies these divergent views? It appears that latent fears about the creation of new life forms do exist, even among the attentives, and that the wording of the earlier question may have activated these fears. For example, the wording of this question presented the creation of new life forms as something that might best "be left alone," possibly conjuring up monsterlike images. In contrast, the risk/benefit question is stated in rather neutral, abstract terms and relates the creation of new life forms to the specific research field of recombinant DNA. It also cites explicitly the benefits that society as a whole may enjoy.[48]

A majority (58 percent) of the nongovernment leaders surveyed in late 1981 believes that the level of government regulation of recombinant DNA research is "about right," although one in six believes that regulation is too high (table 6-13). (This question was not asked of the attentives.) Biological scientists, who are closest to the subject, are more inclined than any other group to believe that government regulation is too strict. Interestingly, 1 in 10 of the biological scientists, and one in five of the physical scientists and a miscellaneous category "other" (mostly composed of humanists, educators, and some health scientists) have no opinion on the level of government regulation in this area.[49] Apparently, these science policy leaders feel that they are not sufficiently knowledgeable about this rapidly changing area of scientific research and policy to offer an opinion.

Nuclear Power

Public controversy about nuclear power is longstanding, with many instances of disputes over siting of nuclear power plants, level of allowable radiation, disposal of wastes, and so on, from the 1960's onward.[50] Public opinion surveys showed that, from 1971 through March 1979, majorities

[44]For an overview of this controversy, see refs. 19, 20, and 21.

[45]See refs. 22, 23, and 24.

[46]See ref. 25.

[47]See ref. 8, table 36. In addition, if the choice had to be made, 60 percent of the leaders would favor funding basic DNA research over applied DNA research in the areas of agriculture and health. See ref. 8, table 38.

[48]Similarly, a strong majority of the general public favors biological and medical engineering to ameliorate genetic defects (table 6-11).

[49]See ref. 40.

[50]See ref. 26.

Table 6-13. Nongovernmental science leaders' views about the present level of regulation of science and technology: 1981
(Percent)

Activity	Too high	About right	Too low	Don't know
New pharmaceutical products	36	49	9	6
Conduct of basic scientific research	26	63	4	7
Construction of nuclear power plants	25	40	33	2
Recombinant DNA or genetic engineering experiments	17	58	9	15
Research involving human subjects	17	63	9	10
Use of chemical additives in food	13	53	29	5
Production and sale of pesticides	12	54	27	8
N = 287				

"Now, I'd like to turn to the general issue of governmental regulation. I'm going to read you a short list of activities and for each one I'd like for you to tell me whether you think that the present level of governmental regulation is too high, too low, or about right."

SOURCE: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 35, 37, 42–46.

or at least pluralities of the public supported the idea of building more nuclear power plants. For a time after the Three Mile Island accident in March 1979, there was more opposition to building new nuclear power plants than support.[51] In later polls, support once more exceeded opposition, but at a level significantly lower than before the accident.[52]

On the whole, the attentive public believes (by a margin of 55 to 45) that the benefits of nuclear power outweigh the risks; the potential attentives are about evenly divided; and the nongovernment science policy leaders strongly believe (by a margin of 60 percent to 30 percent) that benefits outweigh risks (appendix table 6-17).

But opinion on the issue continues to be distinctly polarized. Data are available on how strongly the attentives and the potential attentives feel on the nuclear power risk/benefit question (appendix table 6-18).[53] It is notable that 35 percent of the attentives believe strongly that the benefits of nuclear power outweigh the risks, while almost the same proportion (29 percent) stands at the opposite extreme.[54] Potential attentives also exhibit these extremes of opinion, although negative feelings are more frequent than positive feelings.

[51]See ref. 27.

[52]See ref. 28 and ref. 29.

[53]Unfortunately, parallel data are not available for the DNA benefit/risk question.

[54]In 1979 a similar pattern was noted for attentives. See ref. 9, p. 172. Ambivalence in European attitudes toward nuclear power is discussed in ref. 43.

Distinct differences on the issue also emerge among the subgroups. The higher the education among attentives, the less favorably is nuclear power regarded. This is unusual, since support for science and technology ordinarily increases with the level of the respondent's education. A large middle group of high school and college graduate attentives assesses nuclear power favorably (55 to 45 percent), but with the same polarization as in the group as a whole.

The leaders' assessment of nuclear power, while definitely favorable on the whole, is similarly marked by differences among subgroups. About four-fifths of physical scientists and engineers/medical scientists say the benefits of nuclear power exceed the risks. However, about half of social scientists disagree.[55]

Answers to a question about the regulation of nuclear power tend to confirm the unusual degree of polarization among the leaders on the question of nuclear power. One-third say regulation of nuclear plant construction is too low, while one-quarter regard it as too high. As a later section shows, the leaders' opinion on regulation in other areas is much closer to a consensus. Engineers/medical scientists are the group most likely to think regulation of nuclear power is too high (appendix table 6-17), but even in their case a substantial minority believes regulation is too low. Social scientists are the profession most in favor of more regulation.

[55]See ref. 8, table 34.

Regulation

Government regulation affects many other aspects of science and technology in addition to recombinant DNA and nuclear power. Because of the present reevaluation of government regulation in general, the 1981 survey asked the nongovernment science policy leaders for an assessment of regulation in seven fields related to science.

Majorities of the leaders believe that the present level of regulation is satisfactory in the fields they assessed, except for nuclear power where only a plurality thinks the degree of regulation is satisfactory (table 6-13; cf. appendix table 6-17). In several instances, however, substantial minorities express dissatisfaction. Over one-third believe that regulation of new pharmaceutical products is too high. Leaders particularly affected by regulation in this area are most inclined to think it is overregulated; 48 percent of the biologists, 50 percent of the engineers/medical scientists, and 57 percent of the leaders who work in a for-profit setting say that regulation of new drugs is too strict.[56] Opinion on regulation of the use of chemical additives in foods and the production and sale of pesticides is at the other extreme. About 3 out of 10 leaders consider these areas underregulated at present.

Most leaders regard the level of regulation of research involving human subjects and of basic scientific research as satisfactory. In the latter case, however, a substantial minority (one in four) sees overregulation. As noted earlier, nuclear power is an anomaly on this list, because nearly equal numbers believe that the level of regulation is too high or too low, and only slightly more find it satisfactory.

Space Program

Advances in space technology capture the imagination of many Americans. In 1981, 42 percent in one survey said that they believe "people from Earth will eventually colonize the moon or other planets."[57] In another survey conducted in the same year, 42 percent said that they would take advantage of a chance to travel in outer space if it were offered to them.[58]

After an interval of almost 6 years, piloted space flight was resumed with the first NASA space shuttle flight on April 12, 1981. This venture and the subsequent flights showed that space shuttle technology, with its promise of research, commercial, and military space applications, is feasible. According to a survey conducted less than a month after the first space shuttle flight, 76 percent of Americans judged the success of this flight as "a major breakthrough" for U.S. technology and know-how. The heightened public visibility of the space program during this period occasioned several public opinion surveys on the subject, making it possible to assess the impact of the shuttle successes on public support for the space program. The surveys of potential attentives, attentives, and leaders occurred just after the second shuttle flight in November 1981; the views of these groups can be compared with those of the general public.

The space program is not highly controversial on grounds of risk, but it has been criticized for its cost. Recent surveys show that the general public continues to feel, by roughly two to one, that the space shuttle program is worth its current cost.[59] Asked to assess whether the benefits of the space program exceed the costs, the leaders, potential attentives, and attentives support the program strongly (table 6-14). The potential attentives are about evenly divided on whether the benefits exceed the costs.

Survey data show a close relationship between knowledge and interest in science and technology and support for increased spending for "exploring space." Among the general public, there is relatively little support for increasing spending on space beyond the current levels of expenditures, a historic pattern which the shuttle program has not reversed (appendix table 6-19; cf. table 6-7). Since 1973, the number of those who said we are spending "too little" on the program has varied between 7 and 18 percent, with the latest (spring 1982) data showing 12 percent, a decline from 1980's 18 percent. Results of another survey may explain why more people do not support expansion of the space program's budget, despite the successes of the shuttle program. In spring 1982, just before the third shuttle launch, 46 percent of the general public said that, rather than being excited about the prospect, they "don't care all that much" about space launches.[60] The attentive and potentially attentive public, however, are far more supportive of increased funding for the space program, as shown in table 6-7 earlier in this chapter. Whereas only 1 in 10 of the rest of the public supports more funding for the programs, one in four of the potential attentives and two in five of the attentives favor increased spending.

While in general the nongovernment leaders strongly support basic research with less emphasis on applied research, their preferred priorities in the space program are for service-oriented results. The leaders, the attentives, and the potential attentives were asked whether, over the next 10 years, they would favor satellite systems that offer useful services, such as weather forecasts and communications, or whether they would choose to concentrate efforts on deep space probes "to learn more about the origin and nature of the universe" (table 6-14). Two-thirds of the attentives and potential attentives favor the service-satellite systems. The leaders agree with this position by only a slightly smaller majority (three-fifths).

In sum, the findings reported in this section indicate that, after a brief period of concern and controversy in the scientific community, nongovernment science policy leaders now overwhelmingly believe that the benefits of recombinant DNA research exceed the risks. A substantial

[56]See ref. 8, table 42.

[57]See ref. 30.

[58]See ref. 31.

[59]A Harris poll conducted shortly after the first shuttle flight asked: "It could cost the U.S. Government several billion dollars to develop the full potential of the space shuttle over the next ten years. All in all, do you feel this space program is worth spending that amount of money on, or do you think it is not worth it?" Sixty-three percent said it was worth it, 33 percent that it wasn't worth it, with 4 percent not sure. See ref. 32. Likewise, the NBC News Poll found in two polls that between 60 and 66 percent consider the space shuttle program a good investment for this country while between 26 and 30 percent regard it as a bad investment. See ref. 30.

[60]See ref. 33.

Table 6-14. Views about the space program: 1981
(Percent)

Respondents	A. Cost-benefit assessment				
	Benefits exceed costs	Benefits equal costs[1]	Costs exceed benefits	Don't know	N
Leaders	57	7	27	10	287
Attentives	60	—	38	1	637
Potential attentives	51	—	47	1	617

Respondents	B. Choice of emphasis over next 10 years			
	Prefer more service-oriented satellite systems	Prefer more deep space probes	Don't know	N
Leaders	59	33	8	287
Attentives	68	30	2	637
Potential attentives	66	32	3	617

A. "Many current issues in science and technology may be viewed as a judgement of relative risks and benefits, or costs and benefits. Thinking first about the space program, some persons have argued that the costs of the space program have exceeded its benefits, while other people have argued that the benefits of space exploration have exceeded its costs. In your opinion, have the costs of space exploration exceeded its benefits or have the benefits of space exploration exceeded its costs?

B. "Some space scientists have focused primarily on orbiting satellite systems that can provide useful economic and weather forecasts and communications services. Other space scientists have focused on deep space probes to learn more about the origins and nature of the universe. If it were necessary to place primary emphasis on only one of these two objectives over the next ten years, would you prefer more service-satellite systems, or more deep space probes?

[1] Reported only when volunteered by respondents.

SOURCES: Leaders: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 39 and 40; Attentives: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 26 and 27.

Science Indicators—1982

but smaller majority of the attentive public agrees, while only a plurality of the potential attentives takes this view. Thus, support for genetic engineering research appears to decline with a declining degree of interest in and knowledge about science issues. Half of the attentives and a majority of the potential attentives say they are in favor of restraining research on the creation of new forms of life.

In a somewhat similar pattern, a large majority (two to one) of nongovernment leaders supports nuclear power, while attentives support it less strongly, and the potential attentives are about evenly split. On this highly visible, highly controversial issue, the views of both the leaders and the attentives are distinctly polarized.

Nongovernment leaders appear reasonably satisfied with the degree of government regulation in several areas of science and technology. For six out of seven areas on which they were questioned, majorities of the leaders say regulation is at a satisfactory level. Opinion on nuclear power is greatly divided, but a plurality say regulation of nuclear plant construction is at the right level.

The space program, once more in the news because of the space shuttle flights, has general support. Great majorities of the general public, the attentives, and the leaders consider the program worth the cost.

NONGOVERNMENT SCIENCE POLICY LEADERS AND THE ATTENTIVE PUBLIC

Interest and Knowledge

The criteria used to identify the attentives and potential attentives from the general public sample in the 1981 survey provide some additional insights on the public's interest in and knowledge about science and technology issues. Of the nine issue areas presented for ranking by degree of interest, the general public places "new scientific discoveries" fourth and "the use of new inventions and technologies" sixth as subjects of high interest (appendix table 6-20). Roughly one-third of the public are "very interested" in each of these issues. The level of interest in science and technology has remained steady since the question was first asked in 1979.[61] By contrast, public interest in two other subjects on the list (economics and foreign policy) has shifted dramatically.

People perceive themselves as having a much lower level of knowledge than of interest about science and technology. Only 11 percent of the people interviewed in 1981 consider

[61]See ref. 18.

themselves "very well informed" about new inventions and technologies, and only 13 percent think they are very knowledgeable about new scientific discoveries. Indeed, 37 percent say they are "poorly informed" about science and technology. The contrast between the 38 percent of people who say they are "very interested" in new scientific discoveries and the 13 percent who say they are "very well informed" on the subject is quite striking. Science and technology, in fact, are at the bottom of the self-professed "level of knowledge" list.

Some implications of the knowledge scale used to identify the attentive public are worth noting, as they provide some insight into the level of public scientific literacy. More than one in five of the attentives say they have little understanding of the concepts DNA and GNP (appendix table 6-21). Three in five potential attentives say they have little understanding of DNA or of GNP, and one in four professes little understanding of scientific study. Of the four terms on the table, only radiation appears to be widely understood by the attentives and potential attentives.

Comparisons and Contrasts: Attentives, Leaders, and the Public

The 1981 surveys of attentives and nongovernment leaders show that these two groups share rather similar views on many scientific issues, yet are also divided by some important differences.[62] The similarities reflect a basically favorable attitude toward science—a shared conviction that scientific and technological activities are good for society—and common views about the issues such as the value of the space program, what role industry should play in promoting research, and the priority of science education for Federal funding. The differences regard the way in which scientific advances should be pursued—whether by working on practical problems or by pursuing more fundamental scientific inquiry.

The attentives' assessment of the benefits from science is even more highly favorable than that of the general public, and likewise, attentives are more supportive of scientific activities than is the public in general. Levels of support among potential attentives usually fall between those of the attentives and the rest of the public. For example:

- 90 percent of attentives, 79 percent of potential attentives, and 66 percent of the rest of the public believe that the benefits of scientific research have outweighed the harmful results (table 6-1).
- 49 percent of attentives, 35 percent of potential attentives, and 25 percent of the rest of the public support increased funding for scientific research (table 6-7).

In a like manner, the attitudes of the attentives usually lie between those of the potential attentives and the nongovernment leaders, with the leaders' views most favorable to scientific and technological activites. For example:

- 76 percent of the leaders, 58 percent of the attentives and 47 percent of the potential attentives believe that the benefits of recombinant DNA research outweigh the risks (appendix table 6-16).
- 60 percent of the leaders, 55 percent of the attentives, and 50 percent of the potential attentives say the benefits of nuclear power exceed the risks (appendix table 6-17).
- Only 27 percent of the leaders think the costs of the space program are greater than the benefits, while 38 percent of attentives and almost half (47 percent) of the potential attentives believe that costs exceed benefits (table 6-14). (Polls of the general public show a 2 to 1 majority for the view that the space shuttle program is worth the cost.)

One of the principal differences between the attentives and the leaders is that attentives are less inclined to support basic research. Forced to choose, they would support applied research and utilitarian programs to a greater degree than basic research, and they would accept cuts in funding for basic research proportional to other budget cuts. Te leaders, on the other hand, see basic research as primary: They give high priority among science policy problems to adequate funding for basic research; a majority of them would resist funding cuts for basic research rather than applied research during budget austerity; more of them believe that the United States should be a world leader in "almost all" areas of basic research than in "almost all" areas of applied research.

OVERVIEW

The American general public holds scientific research in relatively high esteem. The opinions of the attentive public—those citizens (20 percent of the general public) who take an active continuing interest in science and technology issues and who are knowledgeable about those issues—are even more favorable. The attentive public believes there is a close tie between basic scientific research and economic growth. "Medicine" and "the scientific community," when compared with other institutions, consistently stand very high in the public's confidence.

The public's view of 'technology' appears a bit more ambivalent. The contributions of science and technology to America's standard of living and to solving problems are highly valued. On the other hand, many Americans express concern that some applications of science can get out of hand, threatening society instead of serving it. On some controversial areas of study—in particular, research that might allow the creation of new forms of life or control over the sex of a child at the time of conception—as much as one-half of the attentive public favors curbs on scientific inquiry. Still, surveys of the general public indicate that Americans desire continued technological advance in most areas, especially health care. The attentive public has high expectations of advance in several areas, such as new sources of energy and cures for cancer, as well as the desalination of seawater and the prediction of earthquakes.

The views of nongovernment science policy leaders are of particular interest, because of their prestige and their expected influence on the public and on decision makers in science policy issues. The nongovernment leaders are

[62] This generalization is based primarily on the relatively limited number of questions which were used in both surveys.

eminent scientists, engineers, doctors, and other professional leaders from universities, nonprofit institutions, and the for-profit sector.Surveyed in depth for the first time in 1981, they express some concern about U.S. world leadership in science and technology. The majority of leaders believes the United States is ahead of other countries in most areas of basic and applied research as well as in science and engineering education. Yet many of the leaders feel that the U.S. position should be stronger than it is, especially in basic research and education.

On nearly all issues, nongovernment science policy leaders gave the most support for scientific and technological activities, followed by the attentive public, and the potential attentives—a group comprising 19 percent of the public who are very interested in science and technology, but somewhat less informed than the attentives. All three groups are even more supportive of science and technology than is the general public as a whole. The attitudes of the attentive public differ from those of the leaders in some other respects: their lesser support of basic scientific research and greater inclination to support applied research directed toward specific practical ends, such as curing specific diseases. Overall, however, the attentive public's regard for science and technology is extremely high.

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Chapter 7
Advances in Science and Engineering

Advances in Science and Engineering

INTRODUCTION

The essays in this chapter seek to convey to the nonspecialist examples of some recent and significant achievements of scientific and engineering research in several selected areas. Its purpose is to supplement and extend the quantitative analyses shown in earlier chapters of this report by giving a qualitative account of certain advances. By focusing on the "substance" of science, a deeper appreciation is conveyed of the nature and need for scientific and engineering research.

Although the articles by no means capture the full gamut of scientific inquiry, the variety of topics discussed is intended to show the great breadth of the endeavor. Some of the topics concern highly abstract fields of inquiry, including recent advances in understanding the fundamental forces and particles in the physical universe and in mathematical techniques to determine in a few seconds on a large computer whether a 100-digit number is prime or composite. Others deal with scientific exploration of hitherto inaccessible realms—the deep ocean floor and, oddly, the surfaces of solid materials. Several of the oldest and most puzzling questions in pharmacology have found an answer with the discovery that the brains of man and the higher animals synthesize natural opiatelike molecules. Finally, many of the advances described in the essays promise important new applications—the development of entirely new materials never found in nature, the chemical fabrication of "baskets" to hold artificial enzymes, and advances in our understanding of early childhood development.

One of the interesting themes that emerges from several of the essays is that progress in virtually all areas of research is vitally dependent on progress in technology. Sophisticated technology provides the basis for most scientific instruments, and certainly for those that contemporary scientists and engineers rely on in their research—including telescopes, particle accelerators, drillships, lasers, and computers. But, of course, basic research underlies progress in frontier technology. Thus, there is a vital synergism between basic research and new technologies; frontier technologies frequently lead to the instrumental capabilities that in turn are required for new advances in basic research. And, of course, the results of basic research frequently lead to technologies that can be incorporated into new generations of scientific instruments.

As the statistical data in this volume make clear, the U.S. undertaking in the sciences and engineering is very large and diverse. By almost every measure, the United States continues to lead the world in scientific and engineering achievement. Yet, it is worth noting that some statistical measures, notably the international comparisons shown in detail earlier in this report, indicate that other industrialized nations may be catching up with, if not already ahead of, the United States in a few fields. In some quantitative measures, such as emphasis on science and mathematics instruction in the secondary schools, the United States is certainly lagging.

Despite weaknesses in a few areas, and evidence that the United States is losing some of the overwhelming preeminence in the sciences, engineering, and technology that it enjoyed during the past several decades, the Nation continues to hold first place in most scientific endeavors. In 1981 and 1982, for example, 9 of 15 recipients of Nobel prizes in the sciences and medicine performed their research in the United States; and 2 of 3 recipients of the 1982 Fields Medals, mathematics' most prestigious award, were U.S. citizens (see tables 7-1 and 7-2). Fields Medals are presented at the International Congress of Mathematics every 4 years to mathematicians under the age of 40. As the following essays will show, the scientific enterprise flourishes as never before, yielding important new findings, deep insights, and significant advances at a rate that seems almost torrential in comparison to the trickle of results achieved in the earliest days of organized scientific inquiry.

PRIME NUMBERS: THE KEYS TO THE CODE

The marriage of electronic communications to the digital computer has launched an "information revolution" in the Western World. Attracted by the speed of electronic transmission and the unique ability of the computer to handle torrents of data, the industrial, financial, and commercial sectors of the United States and other developed countries are rapidly shifting to this new means of shuffling and moving information.

As in every revolution, however, some very traditional odds and ends must be addressed before the revolution can be pronounced a complete success. In this particular revo-

Table 7-1. Nobel laureates: 1981-82

Disciplines	Recipients	Institution/country	Description of research
1982			
Chemistry	Aaron Klug	MRC Laboratory of Molecular Biology, Cambridge, England	Development of crystallographic electron microscopy and structural elucidation of biologically important nucleic acid-protein complexes.
Physics	Kenneth G. Wilson	Cornell University, U.S.A.	Research leading to a theory for critical phenomena in connection with phase transitions.
Physiology or medicine	Sune K. D. Bergstrom & Bengt I. Samuelson John R. Vane	Karolinska Institute, Stockholm, Sweden Wellcome Research Laboratories, Kent, England	Discoveries concerning prostaglandins and related biologically active substances.
Economics	George J. Stigler	University of Chicago, U.S.A.	Seminal studies of industrial structures, functioning of markets, and causes and effects of public regulations.
1981			
Chemistry	Kenichi Fukui & Roald Hoffmann	Kyoto University, Kyoto, Japan Cornell University, U.S.A.	Theories, developed independently, aimed at anticipating the course of chemical reactions.
Physics	Nicholaas Bloembergen, Arthur L. Schawlow & Kai M. Siegbahn	Harvard University, U.S.A. Stanford University, U.S.A. Uppsala University, Sweden	Bloembergen and Schawlow for their contribution to the development of laser spectroscopy. Siegbahn for his contribution to the development of high-resolution electron spectroscopy.
Physiology or medicine	Roger W. Sperry, David H. Hubel & Torsten N. Wiesel	California Institute of Technology, U.S.A. Harvard Medical School, U.S.A.	Sperry for his discoveries concerning the functional specialization of the cerebral hemispheres. Hubel and Wiesel for their discoveries concerning information processing in the visual system.
Economics	James Tobin	Yale University, U.S.A.	Analysis of financial markets and their relations to expenditure decisions, employment production, and prices.

Science Indicators—1982

Table 7-2. Fields Medals recipients: 1982

Recipients	Institution/country	Description of research
Shing-Tung Yau	Princeton Institute for Advanced Studies, U.S.A.	Solution of the Colobi conjecture and the Smith conjecture and work applying the methods of geometry to the problem of general relativity.
William P. Thurston	Princeton University, U.S.A.	Work on the relationship between three-dimensional differential geometry and three-dimensional topology.
Alain Connes	Centre National de la Recherche Scientifique, France	Proof of a version of the Atiyah-Singer theorem, the fundamental theorem of calculus that unifies the fields of topology and analysis.

Science Indicators—1982

lution, there is the problem of maintaining the privacy of communication, since much of it must be safeguarded against fraud, loss of proprietary data, and other harm to legitimate business interests.

Governments routinely encipher sensitive diplomatic and military communications to preserve their security, but at a cost prohibitive to most businesses. What the private sector requires is an efficient, rapid, low-cost enciphering technique, one that avoids the need for couriers to provide communications recipients with elaborate "keys" to decipher transmissions, and one which, if possible, utilizes the awesome number-crunching power of the computer.

One of the most remarkable mathematical developments in recent years is the discovery that prime numbers possess properties that may provide a swift, cost-effective means for maintaining the security of private sector communications. Before describing the enciphering/deciphering scheme based on prime numbers, however, it would be helpful to consider the nature of "primality."

Prime numbers—2, 3, 5, 7, 11, 13, etc.—are those numbers with the property that they are divisible only by 1 and themselves. All other numbers are composite, and all composite numbers are a product of prime numbers, for example, $21 = 3 \times 7$, $45 = 5 \times 3 \times 3$, or $63 = 7 \times 3 \times 3$.

Although the distinction between prime and composite numbers is one of childlike simplicity, determining whether a given number is prime and determining its factors if composite within a reasonable length of time form one of the deepest, most exasperating problems in number theory. Carl Friedrich Gauss, probably the greatest mathematician the world ever produced, observed: "The dignity of the science itself seems to require that every possible means be explored for the solution of a problem so elegant and so celebrated."

That observation was published in 1801, and it remains valid today. While we know quite a bit about the frequency with which primes appear in large sets of numbers, including the fact that they thin out rapidly as the number set grows in size, the precise order or pattern in which primes occur has defied 2,300 years of mathematical analysis. No simple equation to generate the values of all primes has ever been found, nor any efficient means to factor a composite number into its divisors.

There are "brute force" procedures to test for primality and to factor composite numbers in a systematic fashion. One is the famous Sieve of Eratosthenes, named in honor of the astronomer and geographer who tackled the problem in Alexandria about 250 B.C. With this method, one writes down all numbers up to some target value and then strikes out every second digit after two, every third after three, every fifth after five, and so on. Numbers remaining must be prime. Another is trial division—dividing by all numbers less than the square root of the target number to determine what numbers produce a whole number quotient. If the target is 100, for example, the technique will show that it can be evenly divided by 2, 4, 5, and 10, producing whole number quotients of 50, 25, 20, and 10.

Both techniques can identify primes as well as the factors of composite numbers. But both suffer from a grievous limitation: the problem space to be examined varies as a positive power of the target number n (for example, $n^{1/2}$ in the case of trial division), while the amount of information provided as input is proportional to the number of digits of n, the logarithm of n, which grows much more slowly. Mathematicians would say that the problem space to be examined using these techniques increases exponentially with the size of the input.

In practical terms, this means that a 15- or 20-digit number is about the maximum a human mathematician can deal with in an entire lifetime of calculation. Modern computers using faster algorithms can do far better—about 3 months to factor a number of 75 digits. But a 100-digit number would require a time equal to the age of the universe on the most powerful computer available today. The explosive growth of the "search space" eventually defeats our most powerful machines. (See figure 7-1.)

Figure 7-1
Prime and composite numbers

A 97 digit number

6,894,327,798,437,879,653,210,686,143,982,776,298,436,
532,198,932,327,339,651,406,876,597,653,128,965,849,897,
648,976,549,137,657

Is it a prime?

There has been an exciting development in prime number theory during the last several years that has had increasingly dramatic repercussions. It is the discovery that, while the prediction of prime numbers in the general number sequence and the factoring of huge composite numbers remain awkward, techniques have been developed that make it possible to test a given number of huge size for primality, and do this in seconds on a fast computer.

One of the first advances on this new front was achieved by Robert Solovay of the University of California at Berkeley and Volkur Strassen of the University of Zurich and, independently, by Michael Rabin of the Hebrew University of Jerusalem. They devised probabilistic tests that could demonstrate the primality of a given number "for all practical purposes." However, for many traditional mathematicians, the demonstration of an overwhelming statistical probability that a number is not composite is not the same as a rigorous proof that it is a prime number.

These primality tests are based on a result generally credited to the 17th century French mathematician Pierre de Fermat. Fermat noticed that if the number n were prime, then any number b has the property that b^n-b is divisible by n. Unfortunately, a similar result can hold for composite numbers n for (possibly) many values of b, so simply knowing that the result holds for some values of b is not enough to guarantee that n is prime. Knowing it fails for any value of b is enough to show that n is composite. Composite numbers that satisfy this test for a large number of values of b in some sense masquerade as primes and are known as "pseudoprimes."

Tests of this type are ideally suited for machine computation, as at each stage they depend only on the remainder when a number is divided by n. (Mathematicians call this the congruence of the number with respect to n.) Thus, while b^n may be very large, by using congruences at each stage in generating the product, the machine can keep the size of the numbers used in the test within reasonable bounds.

In 1980, Leonard Adleman and Robert Rumely of the Massachusetts Institute of Technology (MIT) found a way to use "pseudoprime" tests to extract information about the target number in such a way that the process could prove primality with all the rigor demanded by traditional mathematics. Moreover, Carl Pomerance of the University of Georgia and Andrew Odlyzko of Bell Laboratories proved that the Adleman-Rumely procedure could be run very

quickly on a typical scientific computer, because it employs an "efficient" algorithm in which the search space grows slowly in relation to the number of digits in the "target" number. Since this work, algorithms based on the Adleman-Rumely procedure have proved the primality of a 65-digit number in times ranging from 6 hours to a few minutes on a moderately fast computer. Most recently, two European mathematicians, Hendrik Lenstra of the University of Amsterdam and Henri Cohen of the University of Bordeaux, created a streamlined version of the procedure and used it to prove routinely the primality of 100-digit primes in an average of 33 seconds each on a large computer.

These swift advances in primality testing coincide with (and have been stimulated by) another development in mathematics with important potential for application in an era increasingly dependent on electronic communications. This is a new technique for enciphering and deciphering coded transmissions to maintain the privacy and message authenticity for both sender and receiver. Unlike traditional military or diplomatic cipher systems, in which the deciphering procedure is immediately obvious when the enciphering procedure is known, the new systems embody a special one-way feature: knowledge of how to encipher the message offers no clue as to how to unravel the "plaintext" from the cipher.

The original concept of the trapdoor cipher was advanced by Martin Hellman, Whitfield Diffie, and Ralph Merkle of Stanford University in 1976. Shortly after this conceptual breakthrough, Ronald Rivest of MIT, Leonard Adleman of MIT and the University of Southern California, and Adi Shamir of the Weizmann Institute in Israel proposed a scheme (the RSA scheme) in which the one-way property could be achieved by basing the cipher on a pair of huge prime numbers p_1, p_2, plus a third large random number q compatible in size and congruence properties to the two large primes. The enciphering key consists of the composite number $n = p_1p_2$ and q. The secret deciphering key consists of p_1, p_2 and q. Using the RSA scheme, messages could be enciphered and deciphered in seconds on a computer, provided users employed the proper keys. The importance of the new breakthroughs in primality testing to the RSA scheme is that they provide a fast way to generate keys for that scheme.

Subsequent to these breakthroughs, Hellman, Diffie, and Merkle devised a different though related trapdoor cipher scheme that involved what mathematicians call the "knapsack" problem—figuring out the precise subset of items that will exactly fill a figurative knapsack of given size. (See figure 7-2.) The knapsack problem belongs to a great class of computational problems known as NP complete problems, in which the search space for any known algorithm grows exponentially with the input size n of the problem, at a rate like 2^n rather than some constant exponent of n like n^2 or n^3 as in polynomial problems. (Other examples of NP problems include the assignment of dormitory rooms, the scheduling of college classes and examinations, and the task of finding the most economical route for a traveling salesman who must visit a number of different cities on a single swing around the country.)

The fascinating feature of both the knapsack and the prime number scheme is that they would permit users to publish their enciphering keys in a directory, since knowledge of these keys apparently conveys no practically usable information about how to decipher the message. This would permit company A to encipher a message in the public key of company B, secure in the knowledge that the enciphered message, even if intercepted by a third party, could only be read by company B. To respond, B would simply reverse the process, enciphering his plaintext message in A's public algorithm. Hellman likens the process to a strongbox with two different combination locks—one to insert the message and the other to extract it.

Figure 7-2
A knapsack problem

Known packages in the knapsack:

20,694
756,713
3,481,140

Items from which contents of packages were selected:

6	289	5,321	95,837
13	632	7,820	247,832
53	943	9,734	439,671
85	1,622	12,285	647,868
194	2,748	46,873	2,832,467

Problem: What is in each package?

Solution:

53+194+943+2,748+5,321=**20,694**
585+632+12,285+95,839+647,868=**756,707**
13+53+289+632+647,686+2,832,467

More fascinating still, the RSA scheme has a wrinkle that permits authentication of A's message to B—a sort of "digital" signature embodied in the structure of the message that could serve as legal proof in a court of law that only A could have originated the message and not some third party. This can be accomplished if A first runs the message through his own secret deciphering key and then through B's public enciphering key. B will then be able to recover the plaintext first by applying his own deciphering key and then A's public enciphering key. The beauty is that neither A nor B will be able to discern one another's secret deciphering algorithms even if doubly enciphered messages are exchanged in this fashion, provided reasonable precautions are taken in the use of the signature. But at the same time, each party would be able to prove in court that only the other could have sent the message, and that the content of the message was beyond the power of either party to alter. Thus, contracts and other agreements arrived at electronically could acquire all the legal dignity of traditional signed instruments.

It is important to recognize that these advances in primality testing, while they provide the means for constructing ciphers, do not solve the longstanding problem of finding divisors of a huge composite number. Rather, these advances permit the swift and economical identification of several hundred digit primes. When such primes are multiplied

together, the product is a composite of enormous size, which at present requires vast amounts of machine time to factor. It is precisely because the factoring problem remains intractable that the fast primality testing techniques are so appealing for the construction of highly resistant ciphers.

The new public-key codes have come under intense scrutiny in recent years. Indeed, Adi Shamir has broken one of the earlier, simpler versions of the knapsack cipher, and Leonard Adleman has broken more sophisticated versions. It is possible that the prime number cipher will be penetrated as well in the constant struggle between encrypters and decrypters. Yet mathematicians and cryptanalysts are in general agreement that new one-way ciphers will emerge that can be rendered so intractable as to make the cost of breaking them vastly in excess of the value of the information obtained. Whether that is a good or a bad thing, only the future can disclose. There is a good deal of fascination in the realization that mathematics, the purest and most fundamental of all the sciences, is finding such immediate and potent application in the ongoing electronic information revolution. Conversely, this information revolution is having a marked effect on the ways that mathematicians work. Until about a decade ago, computers were used in scientific and engineering research primarily to facilitate data gathering from scientific instruments and to analyze those data rather than to produce primary data. That is, computers served as essential adjuncts to other scientific instruments rather than as instruments in their own right, and this remains true today for most science and engineering applications.

However, the speed and memory capacity of the present generation of computers have made possible the numerical solution of problems that could not have been solved previously. Additionally, by offering the possibility of solving such problems, computers have stimulated renewed interest in several areas of theoretical research and have thus led to new and fruitful theoretical concepts.

The field of prime number research as sketched here provides one example of the use of computers as scientific instruments in their own right. Statistical physics provides another. The equations relating certain thermodynamic properties of gases to the behavior of their molecules, for example, involve integrals whose dimensions are equal to the number of molecules in the gas. While the numerical solution of 10^{15}- or 10^{20}-fold intregrals is clearly out of the question for even the largest computers, so-called Monte Carlo methods are available to approximate such integrals. But until a decade ago, these methods also required too much computer time to be used in many applications. Now the situation has changed considerably, as modern computers have begun to solve previously inaccessible problems in statistical physics. The accessibility of such solutions has in turn stimulated renewed interest in several fundamental problems in statistical physics itself. In this way, numerical calculations have assumed a role that is in a very real sense equivalent to the experimental data gathered by other types of scientific instruments. That is, by testing existing theoretical concepts and stimulating new ones, numerical calculations—and the computers that produce them—are leading to exciting and important advances in science and engineering.

THE PURSUIT OF FUNDAMENTALITY AND UNITY

For the better part of the past century, physicists have probed the structure of matter at smaller and smaller scales with instruments of increasing subtlety and complexity in pursuit of the fundamental building blocks of the physical universe. During the past decade, the pace of this quest has quickened as hard-won evidence accumulates that all properties of matter—not only as we know it on earth, but also as it exists in the farthest reaches of the universe and in the cores of the most exotic celestial objects—are describable in terms of the properties and interactions of just two classes of particles: 6 quarks and 6 leptons.

The pursuit of fundamentality has been accompanied by a major step toward another primary goal of modern physics first introduced by Albert Einstein: unification of all the apparently diverse forces of nature into a single interaction that manifests itself in different ways under different conditions. Not only would this grand unification scheme—if it could be realized—encompass all the processes observable today in the physical universe, but, it would relate the properties and interactions of the smallest, most fundamental entities of matter, the quarks and leptons, to the structure of the universe as a whole, and the properties and distribution of matter in the universe to the processes that occurred during the first few seconds of its lifetime.

The language used by physicists to describe both the properties of the most fundamental constituents of matter and the interactions through which they manifest themselves as matter on a larger scale—protons, mesons, atoms, molecules, white dwarfs, or pulsars, for example—is highly mathematical. That language is framed within the context of quantum mechanics, a set of physical postulates and mathematical procedures developed during the 1920's and 1930's to describe the structure and properties of atoms and molecules. Quantum mechanics and its more recent extensions and refinements involve a number of unfamiliar concepts, such as discontinuities in the energy content of nuclei, atoms, and molecules; the convergence of particle-like and wavelike properties of matter and energy; forces that manifest themselves through the exchange of particles; and deep symmetries that have no correspondence in the macroscopic world. Yet the broad outlines of our emerging ideas about the fundamental particles and their manifestations are almost as simple to comprehend as the motivations behind the quest for fundamentality and unity themselves.

As quantum mechanics provides the conceptual framework to understand the fundamental structure of matter, so particle accelerators are the indispensable experimental tools. (For reasons touched upon at the end of this section, astronomical telescopes are also becoming essential in the pursuit of fundamentality and unity.) When the intense, highly energetic particle beams produced by an accelerator are directed onto the nuclei of a target, they induce highly energetic interactions deep within the protons and neutrons of the nuclei. The results of these interactions are then recorded and analyzed by minicomputers that gather

and maintain the raw data recorded by large, sophisticated arrays of particle detectors. In a particularly intriguing extension of the particle accelerator, called the storage ring, beams of protons or electrons collide head on with beams of their respective antiparticles—antiprotons or positrons—which results in the annihilation of the particles as they interact, yielding extremely energetic events.

According to Einstein's most familiar result, a particle of mass m has a rest energy determined by the equation $E = mc^2$, where c is the speed of light. Today, accelerators can speed protons to several hundred times their rest energies, and electrons to several tens of thousands of times their rest energies. From a somewhat different perspective, accelerators can be regarded as exceedingly subtle microscopes. Quantum mechanics associates a wavelength with every moving particle, a wavelength that decreases as the particle's energy increases. Currently the most energetic accelerators yield particle beams with energies equivalent to wavelengths several thousands of times smaller than the radii of protons or neutrons, and thus have the ability to "see" the detailed structure of these nuclear constituents. (See table 7-3.) Wavelengths available from the particle accelerators of the early 1960's were sufficient to probe the detailed structure of atomic nuclei, and more sophisticated accelerators in this energy range continue to be indispensable in nuclear science research. However, those wavelengths are insufficient to yield more than a very fuzzy image of the constituent protons and neutrons. Yet, the data that was emerging from accelerator laboratories in the 1960's about the properties of the proton and neutron were very perplexing indeed.

According to the familiar planetary model established almost 50 years ago, every atom consists of a positively charged nucleus, which is itself composed of charged protons and neutral neutrons (whose masses are approximately equal), surrounded—at distances about 10,000 times the nuclear radius—by the same number of much less massive, negatively charged electrons as there are protons in the nucleus. The electrostatic attraction between the oppositely charged protons and electrons binds the atom into a stable entity. But how can one explain the fact that nuclei themselves exist as stable, composite entities, despite the very large repulsive electrostatic force among their positively charged constituent protons? A relatively straightforward calculation is sufficient to show that the only other force known in the mid-1930's, the attractive gravitational force, is far too weak to neutralize this electrostatic repulsion. Therefore, a new force was conjectured, the "strong" force, as a mechanism for binding protons and neutrons together. Unlike the gravitational and electromagnetic forces that manifest themselves over macroscopic distances, the hypothesized strong force manifests itself only at the nuclear level, that is, at distances less than about 10^{-13} centimeters. But how is this hypothesized strong force transmitted between the constituents of nuclei? By the mid-1930's it had been established that charged particles interact electromagnetically by exchanging photons—"particles" of light. One promising approach to the strong force problem was the suggestion of Hideki Yukawa that the strong force might be mediated by the exchange of a new, hypothetical particle—the meson. But did mesons actually exist?

Prior to World War II, the energies of the beams produced by particle accelerators were sufficient to probe the structure of atomic nuclei and extract information about the interactions of their constituent protons and neutrons, but insufficient to give even a fuzzy picture of the protons and neutrons themselves. Certainly those energies were insufficient to yield any information about the hypothesized mesons. However, very infrequently observed interactions induced by highly energetic cosmic ray particles—

Table 7-3. Highest energy accelerators in the United States

Facilities	Accelerators	FY 1982 Budget (est.) (thousands)	Sponsoring agency
Brookhaven National Laboratory	30 GeV proton Synchrotron (alternating gradient Synchrotron)	$ 75,200	Department of Energy
Cornell Electron Storage Ring	16 GeV electron positron colliding beams	8,100	National Science Foundation
Fermi National Accelerator Lab	400 GeV protron Synchrotron	139,100	Department of Energy
Stanford Linear Accelerator Center	32 GeV electron Linac, 8 GeV colliding electron-positron beam (SPEAR) and 30 GeV colliding electron-positron beams (PEP)	70,400	Department of Energy

NOTE: The rest energy (mc^2) of the electron and proton are 0.511 and 931 million electron volts, respectively. GeV represents "giga" or billions of electron volts.

SOURCE: National Science Foundation, *Status of Science Reviews, 1983.* (NSB 82-260).

Science Indicators—1982

mainly protons originating deep within the galaxy or secondary particles produced by these protons—hinted at complexities that could not be easily accommodated within existing theoretical concepts. In 1947, cosmic ray events were observed that provided clear evidence that the hypothesized meson—now called the pi-meson—did, in fact, exist, although its lifetime in its free state was only a few ten-billionths of a second.

With the advent of more energetic particle accelerators in the late 1940's, it became possible to design experiments to produce pi-mesons in the laboratory and to study them more systematically. Alas, these experiments, as well as cosmic ray events, yielded an embarrassment of riches. For when the protons and neutrons of target nuclei were bombarded with highly energetic particles, they yielded not only pi-mesons, but a host of other mesons as well as a profusion of massive, short-lived cousins of the proton and neutron. By the mid-1960's more than 200 such strongly interacting particles, or hadrons had been identified. Their existence presented physicists with three major problems. First, which of these hadrons, if any, was truly fundamental? Second, could the hypothesized strong force accommodate all the interactions among these hadrons? Finally, what mechanism could be invoked to describe the decay chains of the exotic new particles into sets of familiar particles, including the neutron, proton, electron, photon, and elusive neutrino.

A fruitful approach to the first two of the problems was suggested independently by Murray Gell-Mann and George Zweig in 1963. They proposed that all the hadrons are composed of hypothetical, fundamental entities called quarks: three quarks in the case of the proton, neutron, and their heavier exotic cousins (known collectively as baryons), and two (a quark and an antiquark) in the case of mesons. By assigning a number of distinct properties to these quarks, including electric charges equal to one-third and two-thirds the charge of the electron (or proton), Gell-Mann and Zweig were able to account for many of the most important properties of all the known hadrons. Significantly, their theory also predicted—successfully—the existence of a previously unidentified hadron.

There is, by now, compelling evidence gathered from a number of experiments that quarks actually exist and are, in fact, one of two classes of truly fundamental particles. These experiments have provided indirect though persuasive evidence for five distinct types of quarks, and a sixth has been hypothesized. This evidence is indirect in the sense that no free quark has ever been isolated for individual inspection. Indeed, most theoretical physicists are now convinced that the ways in which quarks bind themselves to one another to form hadrons may forever preclude attempts to extract them. Experimentalists, however, remain hopeful that they can be liberated.

As the quark model was being developed and refined, the search for a framework that could illuminate the last of the three problems—to understand in detail the decay of the new particles—proceeded apace. This search was based on an extension of a model first proposed in the 1930's by Enrico Fermi to describe nuclear beta decay. In this process, a free neutron or a neutron in certain radioactive nuclei is spontaneously transformed, or decays, into a proton, an electron, and a third particle—the chargeless and probably massless antineutrino. Likewise, protons within certain unstable nuclei can decay into neutrons, antielectrons (or positrons) and neutrinos. Fermi's mathematical description of this process was based on the assumption that it could be regarded as an interaction mediated by a new type of force among the four participating particles—i.e., the original untransformed particle and the three product particles. This assumption was later generalized to describe the decays of the unstable particles discovered since World War II. The force that manifests itself through these decays was christened the "weak" force. Like the strong force, this fourth fundamental force can act only over very small distances. Indeed, its range is only about 1/100th that of the strong force. As its name implies, the weak force is far weaker than the strong force. It is also far weaker than the familiar electromagnetic force, although still considerably stronger than the gravitational force.

To reiterate, by 1970, physicists were convinced that no more than four fundamental forces—the strong, electromagnetic, weak, and gravitational forces—were responsible for all interactions among the fundamental constituents of matter and thus for all processes observed or observable in the physical universe. However, only the characteristics of the electromagnetic force and (on a somewhat different level) the gravitational force had been worked out in complete mathematical detail.

Likewise, by 1970, considerable progress had been made toward answering the question: What constitutes a fundamental particle? Since elementary particles, whether truly fundamental or not, manifest themselves only through their interactions, it was natural to classify them according to the types of interactions in which they participate. For example, all particles participate in gravitational interactions. All charged particles can also participate fully in electromagnetic interactions, and composite neutral particles, such as the neutron, participate more subtly. All observed particles can also participate in the weak interactions. However, only the hadrons, composed of the meson and baryon subclasses, can participate in the strong interactions. As such they constitute a distinctive class, but a class that had far too many members prior to the quark model. Now we know that none of the hadrons is truly fundamental.

As of 1970, there were only four observed particles (in addition to the photon, i.e., the quantum of electromagnetic radiation) that did *not* participate in the strong interactions: the electron; the heavier, short-lived muon, first discovered in 1946; and one chargeless, massless (or virtually massless) neutrino associated with each of the two charged entities. Unlike the hadrons, all four of these particles appear to be fundamental in their own right and are classified as leptons. In 1975, a still heavier, short-lived lepton, the tau, was discovered at an experiment conducted at the Stanford University storage ring. Symmetry demands that a third neutrino be associated with this third charged lepton, although as yet it has escaped detection.

Thus, today we have good reason to believe that there are but two classes of truly fundamental particles: six types of quarks and six types of leptons, together with six accompanying antiparticles in each class. This is a considerable simplification from the situation 20 years ago when there

appeared to be 200 odd "fundamental" hadrons and four leftovers lumped together into a lepton class.

However, as so often happens in science, advances in solving one set of problems very often stimulate whole new sets of questions. How, for example, can complete mathematical descriptions of the strong and weak interactions among the fundamental particles and their simplest constituents be formulated? Can the number of fundamental forces be reduced to less than four? Is it simply a coincidence that there appear to be exactly the same number of quarks as there are leptons, or is there a deeper significance to this correspondence?

Although complete answers to these three questions remain to be found, those answers appear to be related. Indeed, by the late 1960's, a partial answer to the second question had already been formulated and awaited experimental verification. Sheldon Glashow, Steven Weinberg, and Abdus Salam, working independently, had developed a theoretical framework that unified the electromagnetic and weak forces into a single electro-weak force. At sufficiently high energies there should be, according to this theory, no distinctions at all between the electromagnetic and weak interactions among the fundamental particles. However, at the energies that characterize most interactions in the laboratory, the electro-weak force manifests itself in two separate but closely related ways.

Several major predictions made by Glashow, Weinberg, and Salam were verified at high-energy accelerator centers during the 1970's. The theory requires that there be a precise correspondence between the electromagnetic interactions of a charged lepton with protons and neutrons and the weak interactions of the corresponding neutrino with those entities. The scattering of neutrinos was first measured in 1973 and found to correspond, in its magnitude, to the scattering of electrons in a manner predicted by the electro-weak theory of Glashow, Weinberg, and Salam.

The theory also requires that the scattering of electrons from protons and neutrons should be mediated in an exactly predictable way by both the electromagnetic and the weak interactions between the particles. One way to detect the relatively insignificant contribution of the weak component of the electro-weak force is to search for a difference in the scattering of high- energy electrons from deuterons (i.e., bound states of protons and neutrons) that depends on the polarization of the electrons—the orientation of their spin axes. Any such difference is completely attributable to the weak interactions. In 1978, the exceedingly small difference predicted by Glashow, Weinberg, and Salam in the scattering of polarized electrons from deuterons was finally observed.

Recently, Carlo Rubbia of Harvard University and the Center for European Nuclear Research (CERN) reported on the observation of the charged "w particle," long hypothesized to be the carrier of the weak force associated with the decay of nuclei and elementary particles. (See figure 7-3.) In highly energetic collisions of protons and antiprotons, a large team of U.S. and European physicists found events which signify the decay of a particle into an electron and neutrino. The number of events and the mass of the decaying particle fit the prediction of the Glashow-Weinberg-Salam unified theory of weak and electromagnetic interactions.

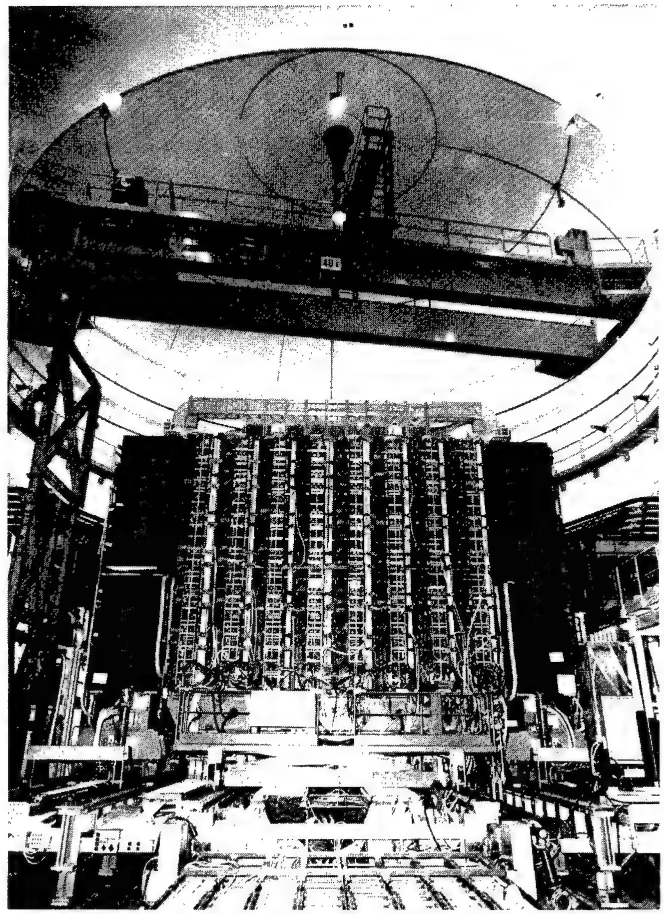


Figure 7-3
Accelerator at the Center for European Nuclear Research where the charged "w" particle was first observed.

SOURCE: Photo CERN

The success of the electro-weak theory earned the Nobel Prize for its three originators in 1979. Moreover, it has spurred the search for a grand unification theory that would embrace not only the strong and electro-weak forces but ultimately the gravitational force as well. The search for grand unification remains elusive, in part because a completely satisfactory theory of the strong interactions among the quarks has yet to be formulated. However, all serious contenders for what could ultimately be the basis of a grand unification theory have several features in common.

First, they assume that at *extremely* high energies there would be one and only one type of force among the fundamental particles. However, at progressively lower energies the gravitational force, then the strong force, and finally the weak and electromagnetic forces would begin to manifest themselves.

Second, all these proposals—in common with the electro-weak theory—are based on a deep symmetry principle known as local gauge invariance, and local gauge invariance requires that every type of quark be coupled with a distinct type of lepton.

Third, all grand unification proposals predict that protons should be very slightly unstable, decaying with lifetimes, however, that are so long compared with the age of

the universe that the effects of those decays would be minuscule on a human time scale.

Is the search for grand unification based on anything more than an understandable aesthetic desire to understand nature at its most fundamental level? The energies at which the strong and electro-weak force would combine into a single electronuclear force are well beyond the reach of any particle accelerator likely to be constructed, and the gravitational force would merge with this electronuclear force at even more excessive energies. What significance, then, could grand unification have for matter as we know it?

While these excessive energies do not and almost certainly will never exist on earth, they are approached and at one time may actually have existed in other parts of the universe. The energies in the interiors of extremely dense neutron stars or pulsars, for example, are sufficient to require that even though the electromagnetic and weak interactions among the fundamental constituent entities may not be completely merged, the correspondence between their manifestations should be much more similar than on earth. A complete grand unification theory would provide detailed information about that correspondence.

More dramatically, according to the so-called Big Bang theory, the universe as we know it has evolved from an exceedingly dense concentration of energy that began to expand about 16 billion years ago. Prior to its expansion, the energy of the proto universe would have been so high that only one single, fundamental force would have been manifest. Upon expanding, the energy density of the proto-universe would have decreased at such a precipitous rate that, within the first few seconds, the single, unified force would have begun to manifest its four separate aspects. Another 100 million years would have elapsed before the universe was cool enough for atoms to form, and still another billion before the first proto-galaxies could have begun to emerge. Yet the processes that occurred as simplicity began to give way to complexity during the first seconds would have left an indelible imprint on the subsequent history of the universe, and on the forms of matter we observe today.

One example should illustrate the intimate connection between the fundamental particles and their interactions on the one hand, and the grand structure of the universe on the other. According to present cosmological thinking, the universe could not have evolved from the energy-dominated form that existed during the first few hundred thousands or millions of years after the Big Bang to its present matter-dominated form if protons were completely stable. But all proposals for grand unification predict that protons should, in fact, be slightly unstable. Thus, the search for experimental evidence of proton decay is proceeding apace, for that evidence would help rationalize the Big Bang theory. In addition, it would serve as a further impetus in the search for grand unification theories.

During the past half century, the pursuit of fundamentality at ever-decreasing scales has led to many surprising pieces of puzzles, which, when assembled, have resulted in a more significant understanding of the unity of the universe. Interestingly, this pursuit has also served to unify to some degree the disciplines of particle physics, which focuses on the properties of the smallest constituents of matter, and cosmology, which is concerned with the overall structure and history of the universe. For this reason, modern day astronomical instruments—including ground-based optical and radio telescopes as well as satellite-borne optical, X-ray, and gamma-ray telescopes—have become important tools for particle physicists, as particle accelerators are providing important data for cosmologists. (See table 7-4.)

Table 7-4. Large astronomy centers in the United States

Centers	FY 1982 Funding Levels (thousands)
National Astronomy Centers:	
National Astronomy and Ionsophere Center ...	$ 5,300
Kitt Peak National Observatory and Cerro Tololo Inter-America Observatory	17,300
National Radio Astronomy Observatory	14,800
Sacramento Peak Observatory	2,000
Major Astronomy Centers:	
Clark Lake Radio Observatory	399
Five College Radio Observatory	850
Hat Creek Radio Astronomy Observatory	853
Millimeter Wave Observatory	400
Mount Lemmon Observatory	234
Multiple Mirror Telescope	950
Owens Valley Radio Observatory	1,601
Smithsonian Astrophysical Observatory	8,660

SOURCE: National Science Foundation, *Status of Science Reviews, 1983* (NSB 82-260).

Science Indicators—1982

No one expects that a complete, consistent grand unification theory will emerge soon or come easily. But most physicists—and astronomers—believe that the pursuit of fundamentality and unity will continue to lead to even deeper insights into the intimate relationships between the universe on its smallest and grandest scales.

THE SCIENCE OF SURFACES

Water, H_2O, is extraordinarily tenacious toward dissociation into its component atoms, hydrogen (H) and oxygen (O). Heat will convert liquid water into steam at 212°F, but enormous amounts of additional heat are required to tear the H_2O molecule apart. In fact, at 2,700°C, only 11 percent of the water will have dissociated. However, if the water is superheated in a steel container, its dissociation proceeds much faster and at a far lower temperature. This is a result of a reaction between the water molecule and the iron surface of the steel container, which forms Fe_3O_4, rust, on the surface, and hydrogen gas.

The steam-iron reaction is but one example of the critical role surfaces play in thousands of chemical processes. Here, iron actively joins in the formation of the end-product, iron oxide; its role is that of a reagent. But there are a great many other important processes in which iron serves as a catalyst, that is, as an arranger or matchmaker for a reaction between two different chemical species to form a new compound of which iron is not a part. One of

the most famous of these was introduced in 1913 by Fritz Haber and Karl Bosch to synthesize ammonia, NH_3, from atmospheric nitrogen and hydrogen in the presence of iron catalyst. The process, $N_2 + 3H_2 \rightarrow 2NH_3$, operates at extremely high temperatures and pressures, 550°C and 200 atmospheres. Its achievement taxed to the limit the chemical engineering technology of the day, but it freed Germany from dependence upon foreign sources of nitrates to manufacture explosives and fertilizers.

The unique role of catalysts was first recognized in 1836 by the chemist Jacob Berzelius. It was apparent that all the action occurred at the surface of the catalyst, presumably when reactant atoms came into close proximity with active sites. But chemists had no fundamental knowledge of the nature of surfaces, or indeed of atoms themselves. Until quite recently, they lacked the analytical tools necessary to obtain such knowledge. Nevertheless, because of the great economic importance of catalytic processes, chemical engineers developed an impressive body of empirical data enabling them to employ catalysts in increasingly sophisticated and efficient ways.

Paradoxical as it may seem, solid surfaces have been far more inaccessible to scientific investigation than the interior of bulk solids. One reason is that there are far fewer surface atoms that can be probed. Another reason is that it is impossible to conduct surface experiments at atmospheric pressure or even moderate vacuum. A surface will film over almost instantaneously with a layer of oxides before useful measurements can be made. In fact, even in a vacuum of a hundredth of a millionth of an atmosphere, there is still enough residual gas to cover the surface with a monolayer of contaminant. Thus, progress in understanding fundamental processes at surfaces had been at a virtual standstill since Berzelius' time until the development of ultrahigh vacuum techniques 15 years ago. With the new technology, vacuums on the order of a trillionth (10^{-13}) of an atmosphere could be attained, allowing experiments to last up to several hours before the surface ions contaminated.

Now, what is the geometrical arrangement of surface atoms? Suppose a well-characterized crystalline solid is cleaved along one of its crystallographic planes. What had been the bulk is now a new surface. Importantly, the chemical bonds linking one plane in the crystalline solid to the next have been severed. As a result, the freshly cleaved surface is highly reactive, i.e., the surface atoms rearrange themselves in more "comfortable" positions in 2-dimensional space. The result is that the order they exhibit is no longer that of the bulk solid. But how are these new structures studied? It is not surprising that progress in the field is closely identified with the development of techniques exploiting various atomic-scale probes. These probes include X-rays, electrons, ions, neutral atoms, neutrons, positrons, and even superhigh frequency sound waves.

The diffraction of both low- and high-energy electrons by surfaces has proven most effective for examining surface geometry. When the diffracted electrons strike a phosphor screen, they produce patterns of spots from which the symmetrical arrangement and size of surface atoms can be determined. Neutral and charged helium atoms are particularly useful for determining how the two-dimensional adsorbate "shadows" the underlying surface substrate atoms; the angle of scattering of these particles from adsorbates discloses their geometry on the corrugated surface and, thus, the sites to which they preferentially bind. Another method, extended X-ray absorption fine structure (EXAFS) uses X-rays to eject electrons from foreign adsorbate atoms. These scatter backwards off the underlying metal surface atoms toward a more central adsorbate atom. By measuring the probability of absorption of X-rays by the foreign adsorbate as the X-ray energy is varied, the location of "nearest neighbor" metal surface atoms can be determined.

Bulk solids are readily characterized by X-ray diffraction techniques, but, until very recently, these techniques could not be employed successfully to measure the very weak X-ray interaction with surface atoms. The availability of extremely powerful synchrotron radiation sources now offers a way around this old roadblock. Additionally, the need to have such sources for research in surface science has broadened the utility of electron acceleration, whose indispensibility to particle physics research was touched upon in the preceding section on Fundamentality. When electrons are accelerated to high energies and maintained in circular orbits by intense magnetic fields (as they are in all storage rings as well as in circular accelerators), they lose part of their energy in the form of synchrotron radiation. Such radiation is intense, highly directional, and dispersed across the infrared, optical, ultraviolet and X-ray portions of the electromagnetic spectrum. Ports located at intervals along the circumference of a circular electron accelerator permit the emergent synchrotron radiation to be used for a host of experimental purposes. Monochromators at the ports can be used to filter out all but the desired wavelengths. If X-rays from such a source are allowed to graze surfaces at very low incidence (less than 1 degree), they can turn the weak X-ray absorption of surface layers to great advantage and characterize the geometry of adsorbates with high accuracy.

Other powerful techniques have been introduced to determine the distribution of the outer, most weakly bound electrons of a surface atom. It is these "valence" electrons that form bonds between atoms—the domain of molecular chemistry. The distribution, density, and energy of these states determines the electronic structure of surface atoms, a subject of profound importance to the design of both catalysts and semiconducting electronic devices.

Techniques have also been developed that determine the composition of surfaces to a precision of 1 atom in 100. For example, ion scattering spectroscopy bombards the sample with ionized helium atoms carrying a net positive charge. By measuring the energy of the helium ion before and after collision as well as the angles of incidence and reflection, the nuclear mass of the "target" atom on the surface can be uniquely determined, and thus its chemical identity. Other methods employ X-rays to break core electrons free of their innermost "orbits" around the nuclei of the surface atoms; the energy of these electrons is a measure of the binding energy required to hold them in close orbit and thus a fingerprint of the chemical identity of the nucleus. High-resolution electron energy loss spectroscopy identifies not only the atomic nature of the surface but the molecular characteristics as well. It allows the vibrational spectrum of adsorbate on the surface to be determined.

This process of adsorption and diffusion is of intense interest because of the fundamental role it plays in the catalytic dissociation of molecules and their recombination into new molecular species. The catalytic converter in the exhaust systems of automobiles employs a thin film of platinum to dissociate oxygen molecules (O_2) and to adsorb both individual oxygen atoms and carbon monoxide (CO) molecules. The latter are sufficiently mobile to migrate about the surface. When they encounter one another, they combine to form carbon dioxide (CO_2), a self-sufficient molecule with no extra bonds to share with the platinum atoms. The CO_2 is released from the surface and emitted in the exhaust, making new sites available for additional O_2 and CO to adsorb to the platinum catalyst.

Other methods, for example, field ion microscopy, are invaluable for determining the diffusion of adsorbates both across surfaces as well as into deeper layers below the surface. The latter process tends to segregate and concentrate impurities at the edges of crystal dislocations; it plays a crucial role in such processes as corrosion and embrittlement of structural materials.

Nowhere has the battery of powerful new techniques generated more spectacular advances than in the manufacture of semiconducting materials under precisely controlled conditions. Because of its great ease of fabricability and the seemingly limitless density with which microcircuits can be etched into alternating p-type (electron-deficient) and n-type (electron-rich) layers, silicon presently is the overwhelming choice for semiconducting devices. But there are other interesting combinations of elements under investigation, notably the Group III-V elements of the periodic table. Aluminum, gallium, and arsenic are among the elements of Group III; when one of these is formed into a binary compound with a Group V element such as phosphorous, arsenic, or tin, superior superconducting properties can be achieved. Not only do the binary semiconductors permit construction of devices with unique electro-optical properties, such as injection lasers, light-emitting diodes (LEDs), photodetectors, and solar cells, but they also make possible a three- to five-fold increase in the speed of information processing on microcircuit chips.

Even more remarkable than the devices themselves is the aggregation of techniques employed to achieve unprecedented control and precision in their fabrication. This technology is entirely the fruit of basic studies in surface science over the past decade, and there is no way it could have been developed in the absence of this kind of fundamental inquiry.

For example, most semiconductor chips available today are etched by photolithographic techniques, which means that the minimum dimension of an etched "wire" ranges from 2 to 5 microns because of the wavelengths of the visible light employed in the etching process. By utilizing far more sophisticated techniques, it may be possible to etch reliable circuits whose dimensions are a hundred or even several thousand times smaller. In theory, devices of this type would be capable of handling enormously greater amounts of data at greatly increased speeds than the present state of the art, the 64-kilobyte random access memory (RAM), can handle. A national facility for submicron research has been established at Cornell University to focus scientific and engineering efforts on how to make very tiny structures as well as on learning what happens when circuits are compressed to a few atomic diameters in width. Structures fabricated on this scale are expected to display fascinating properties due to the crossover from the quantum regime to the behavior of microscopic objects.

Epitaxy techniques provide a second example of the degree of control that is now available in the fabrication of special materials. Epitaxy is the process of crystal growth in which the periodicity and orientation of a crystalline substrate "fixes" these properties in new layers grown upon it. The ingredients of each layer may be deposited in vapor or liquid form, but the most exquisite control can be achieved in a process called molecular beam epitaxy (MBE). In MBE, all the materials required for crystal growth are supplied in the form of molecular beams emitted by effusion ovens equipped with shutters to regulate beam intensity. As many as six ovens are mounted in a cold-wall vacuum chamber so their beams will fall on the substrate, whose temperature can be controlled to optimize crystal growth. The process is conducted in an ultrahard vacuum to minimize contamination by impurities.

The surface science technique called high-energy electron diffraction (HEED) is used to monitor crystal growth and regulate beam intensity, temperature, and other properties in the chamber. An electron gun is aligned on one side of the chamber at an oblique angle to the growing crystal; as electrons collide with the surface atoms, they are diffracted, and the patterns they produce are displayed on a fluorescent screen, providing continuous, real-time information on the state of the growing crystal and permitting the deposition of layers possessing a smoothness vastly exceeding that of the best mechanically polished substrate on which crystal growth begins.

In addition to the main ingredients for crystal growth, for example, gallium and arsenic, the effusion ovens also contain impurity substances or dopants having a surplus or a deficit of electrons. These can be incorporated as required to produce the n-type or p-type conduction layers of the semiconducting device. As the process proceeds, the relative intensity of the beams can be altered abruptly, producing "heterojunctions" so sharp that a gallium arsenide layer only 100 atoms thick will vary by only one or two atoms over its entire surface. In this way, a device can be grown having all the properties of a single crystal, that is, despite the variation in atomic components in the various layers, all layers exhibit a matching geometrical lattice structure.

With MBE, it is possible to construct semiconductors without the use of specific dopants. Some Group III-V element combinations, such as gallium antimonide and indium arsenide, have sufficiently different electronic structures so that alternate, sharply defined layers will provide a high mobility semiconducting superlattice. In this case, gallium antimonide is the n-type material; its electrons spill over into the p-type layer of indium arsenide, while "holes" in the latter migrate into the gallium antimonide. Extremely thin films made of these materials offer the fundamental scientist an unprecedented opportunity to study the behavior of what is essentially a two-dimensional electron gas with properties remarkably different from the three-dimensional electron gas pervading ordinary solid materials. Thus, the same technology generated by the most fundamental studies in surface science is yielding

new materials with properties of deep interest to the surface sciences. Each is enriching the other, to their great mutual benefit.

MANMADE BASKETS FOR ARTIFICIAL ENZYMES

A century ago, cities in the United States and Europe relied on coal gas for municipal illumination. A familiar figure was the lamplighter who made his rounds at twilight with an interesting gadget on the tip of a long pole—a flameless igniter. Its active element was a very finely divided platinum dioxide, known as platinum black. Held in the stream of hydrogen and carbon monoxide issuing from the gas jet, it could ignite the hydrogen at ambient air temperature.

The platinum particles performed a catalytic function, oxidizing the hydrogen at very much lower temperatures than would be required for ignition by conventional flame. Catalysts vastly accelerate the rate of chemical reactions without themselves entering into the end product of the reaction. They do this by dissociating molecules that bind strongly to them and then recombining the bound intermediates into new molecules whose bonds are complete, allowing them to leave the surface of the catalyst to make room for new "feedstock." Catalytic processes are of vast economic importance, playing a key role in petroleum refining and reforming, in the manufacture of ammonia for fertilizers, in petrochemicals, and in a great variety of other chemical processes.

As impressive as these manmade catalysts are, however, they are vastly surpassed by nature's own catalysts, the protein enzymes of all living organisms. Unlike most of man's catalysts, which often operate only at very high pressure and temperature to achieve their efficiency, nature's enzymes are limited to the very narrow range biological organisms can tolerate, mostly from 10°C to 50°C, and, except for ocean-bottom dwellers, to pressures on the order of one atmosphere. Despite these relatively restricted but mild conditions, it is not unusual to find enzymes that can accelerate reaction rates by factors that range from 1 billion to 10 billion over those that would occur in the aqueous environment of the cell in the absence of the enzyme.

Nature's superiority over man's in designing catalysts is understandable when one recalls that it has been in the business of engineering living organisms for at least 3.5 billion years. Human science did not even recognize the existence of "organic chemistry" until Frederich Wohler's synthesis in 1828 of a biological compound, urea, from nonbiological starting materials. Prior to that time, living organisms were seen as fundamentally different from the realm of inorganic chemistry and not subject to chemical principles.

One of the greatest challenges facing modern chemistry is to understand the fundamental nature of catalytic action. Much of our present knowledge is empirical in nature. We know that some catalysts work supremely well and others indifferently. Except for a few catalysts that have been very thoroughly studied, we can claim a fundamental understanding of only a few of the hundreds of catalytic systems that have been identified.

One of the curious and fortunate things about science is that when there are advances in one discipline, they are often achieved in "nearby" disciplines in a way that sheds considerable light on the fundamentals of the problem. Over the past three decades, a number of quantum leaps have been achieved in the new field of molecular biology, several of which have elucidated the structure and dynamics of enzyme operation in the biological realm.

Using X-ray diffraction, Max Perutz of Cambridge University painstakingly worked out the spaghettilike structure of the hemoglobin molecule of horse red blood cells. Tucked deep within its folds are four heme groups—iron atoms surrounded by rigid rings of nitrogen atoms. These hemes bind oxygen in the lungs, transport it to the peripheral tissues, and unload it, picking up carbon dioxide for the return trip to the lungs. Here the carbon dioxide is liberated, permitting the hemoglobin to pick up a new cargo of oxygen for the muscles and tissues.

The Perutz model of the hemoglobin molecule provided several important insights. One is that the highly folded and skewed structure of the protein containing the highly reactive iron hemes plays a crucial role in preventing oxygen and carbon dioxide from binding so tightly to the iron atoms that they cannot be dislodged. The "cargo" is allowed to get just close enough to form bonds, but not to become inextricably attached. Another important finding was that the large hemoglobin molecule experienced a significant structural change between its "deoxy" and its "oxy" conditions. In the first, the iron atom remained tucked neatly within the plane of its surrounding nitrogen atoms; in the second, it flipped out of plane about 0.75 angstroms. This structural mobility, resembling the spring action of a child's cricket toy, caused the French molecular biologist, Jacques Monod, to call hemoglobin an "honorary enzyme," because he was convinced that such structural alterations were essential to enzyme functioning.

These findings in biology have provided much guidance and inspiration for organic chemists seeking to understand catalysis. They have led to a number of ambitious efforts to synthesize chemical "baskets" capable of holding reactive atoms or molecules (catalysts) and controlling access of substrates (reactants) to them. This new field is called "host-guest" chemistry, because its object is to synthesize host structures for guest catalysts. Both host and guest are structurally manipulatable, and the host-guest complexes lend themselves to detailed examination. Molecular designs combined with mechanistic studies promise to provide more than the "stuff of which dreams are made" and just possibly they may provide manmade catalysts superior to those produced by hit-or-miss techniques.

Very few of the 2 million chemical compounds synthesized to date exhibit a concave, inwardly curving surface. Like stones found in streambeds or on ocean shores, most display convex or rounded shapes, their chemical bonds projecting outward like spines to link with attached atoms. A few natural compounds like the aromatics do have flat or nearly flat ringlike structures. Perhaps the most distinctive of the aromatics is benzene, which possesses a two-dimensional hexagonal structure comprising six carbons and six hydrogens. However, concave structures with inwardly directed bonds are con-

spicuously missing from the long list of manmade compounds.

Donald J. Cram of the University of California in Los Angeles wants to remedy this deficiency. He has undertaken to synthesize a class of compounds he calls "cavitands" with enforced cavities having dimensions at least equal to the smaller atoms and molecules. As he explains the task, "One of the supreme challenges to the organic chemist is to design and synthesize compounds that simulate the properties of the working parts of evolutionary chemistry." The reaction of an enzyme with a substrate (reactant) to form a complex is a central feature of the catalytic process. "Cooperativity between catalyzing functional groups in enzyme systems is possible only if those groups are held in positions which converge on a substrate-binding site, usually located in a cavity." The design, synthesis, and study of these organic cavitands is the principal theme of host-guest chemistry.

Compounds called "chorands" and "cryptands" that ordinarily possess folded structures with no cavities have been synthesized. When they come in contact with suitable metal cations they unfold, and the metal ions neatly occupy the cavity they have induced to form. The process resembles dressing, during which folded cloths become enveloping cloths as their interiors are filled. Cram's cavitands are a third class, including "spherands," whose cavities are formed during synthesis and prior to complexation with appropriate metal ions or molecules. The backbone of his simplest cavitand consists of a circular arrangement of six benzene rings. Six methoxy groups (CH_3O) project inward into the cavity, one from each of the benzene rings. Because of spacial constraints, the six methyl groups (CH_3) turn outward and the oxygens inward in an alternate up-down-up-down (octahedral) arrangement. The total cooperative effect of this assembly is to prevent all but very small rotations about the bonds and to compel the unshared electron pairs of the oxygen atoms to line a spherical cavity surrounded by a "skin" of benzenes and methyls. Because of the restricted cavity size, the six-benzene cavitand readily complexes with lithium and sodium ions (Li+ and Na+) but not with the larger potassium, rubidium, cesium, magnesium, or calcium ions. Thus this spherand exhibits a high degree of structural recognition. The structure resembles that of a thick snowflake with a hole in the middle, which is clearly visible in the crystal structure of the compound.

Cram has constructed larger collar-shaped cavitands containing a nearly rigid framework of eight instead of six benzene rings; the eight oxygens attached to the benzene rings are directed generally toward the center as before, but their associated methyl groups are less congested and have the mobility to project either inward or outward from the center of the molecule. The resulting cavity can assume a variety of shapes, depending on the demands of its guest occupants. The cavity dimensions can vary from 2.5 by 4 angstroms to 3 by 8 angstroms. This host complexes the differently sized cesium, potassium, and sodium picrates, exhibiting different levels of binding energy in each case depending on whether the "fit" is tight or loose.

More complex collars that employ naphthalene units instead of simple benzene rings to assemble the macroring have been constructed. Each naphthalene has an enforced planar structure larger than benzene. When naphthalenes are attached to one another, their spacial requirements force them into a noncoplanar arrangement whose cross sections resemble open scissors. In the spherand containing eight naphthalenes, the eight oxygen atoms project into the cavity as in the eight-benzene structure, but the cavity is larger, enabling it to accommodate large molecules like cyclohexane. The ten-naphthalene structure with ten inwardly projecting oxygens forms a still larger cavity. The placement of these ten oxygens is complementary to the ten hydrogens of the ferrocene molecule ($C_5H_5FeC_5H_5$), and a scale molecular model of ferrocene exactly fits into a model of the ten-naphthyl spherand with all the methyl groups rotated outward from the cavity. Ferrocene is of considerable interest in its own right, because the lone iron atom is sandwiched between two parallel, symmetrical rings, each composed of five CH groups.

While the larger collarlike cavitands can accommodate some simple organic compounds in principle, all the guests "imprisoned" so far are metal ions. This has led Cram and his associates to consider the possibility of synthesizing both totally-closed and partially-closed cell-like hosts to see if these can encapsulate organic guests. Of particular interest are the nature of the host-guest interactions, the type of reactions that can be carried out on enclosed guests, and whether cavitands can be prepared with "pores" permitting certain guests to enter but barring passage to others. They have considered a variety of benzene-based structures bridged in up to four places by groups such as methylene (CH_2) or oxydimethylenes (CH_2OCH_2) that can be assembled into roughly spherical, rigid, entirely closed cavitands. One theoretical structure would contain 12 benzene rings and 24 methylene groups, $(C_6H_2)_{12}$ $(CH_2)_{24}$. Only the tiniest of atomic and chemical entities—electrons, protons, diatomic hydrogen (H_2), and lithium ions—could enter its roomy interior through pores.

But if one or more of the benzene rings and their associated methylene bridging groups is removed, a variety of different shapes can be produced, varying in form from pots, bowls, and vases to simple saucers. So far, organic chemists have constructed several types of three-and four-benzene saucers. Cram's group and other chemists have used these "foundations" to build more elaborate bowl- and vase-shaped structures as well as cleft, open-ended cylinders. It should be possible to manipulate the many different characteristics of the binding sites of the hosts as well as their overall geometry to attract and orient specific organic "target" guests while rejecting others.

"One of the incentives for the exploration of host-guest complexation chemistry is the expectation that organic catalysts of the future will combine binding and orientation with cooperativity between catalytic functional groups," notes Professor Cram. "We believe that structural recognition in complexation and catalysis will depend on hosts whose structures are subject to a minimum of ambiguity with respect to the sizes and shapes of their cavities and the locations of their catalytic sites."

Ronald Breslow of Columbia University has concentrated on the development of artificial enzymes capable of approaching both the superb selectivity and the enormous acceleration of reaction rate (on the order of 10 billion-

fold) found in natural enzymes. For a number of years, he and many other chemists have looked upon the cyclodextrins as an ideal tool for this work. Cyclodextrins are natural products formed by bacteria. Consisting of six, seven, or eight glucose units ($C_6H_{10}O_5$), they form an open-ended collar or cylinder 7 angstroms deep, but 5, 7, and 9 angstroms in diameter, respectively. The cyclodextrins have the interesting property that many hydroxyl (OH) radicals rim the cavity, making it "hydrophilic," that is, soluble in water. At the same time, however, the interior of the cavity is "hydrophobic," or water-repelling, so that it presents an attractive invitation to small organic molecules with suitable bonds and hydrophobic inclinations to "come into the parlor and get dry."

Early work with these structures focused on the ability of the hydroxyl groups on the rim of the cylinder to mimic the first step in an enzyme's attack on a bound substrate. The rate of hydroxyl attack in one of nature's enzymes can occur millions of times faster than the attack on the substrate by simple solvents. Until recently, all examples of cyclodextrin-promoted reactions on various substrates did not exceed disappointing accelerations of 300-fold.

Breslow and his associates undertook a detailed study of this poor performance, initially using the ester, meta-ter-butylphenyl, acetate as a substrate. Molecular models showed that the ester bound tightly into the cyclodextrin cavity, but that successful hydroxyl attack on the carbonyl component of the ester required that the entire molecule be pulled up out of its most stable binding position. They had a situation in which the substrate was more tightly bound than in its transition state in which the hydroxyl attack is most effective; according to the chemist, Linus Pauling, the ideal situation is one in which the transition state is more tightly bound than the substrate.

As a first step, the investigators modified the cyclodextrin collar by building a "floor" into it, making it a closed pocket shallower than the unmodified system. Although it binds less deeply, the substrate is still strongly bound because of the contribution of the new "floor" to the binding. In another step, they attached additional projecting groups to the ester substrate to prevent it from binding deeply in the cavity. These steps brought the geometry closer to the ideal situation, accelerating the reaction rate 4,000-fold relative to the rate in solvent only. In a third series of steps, they turned from ester substrates to novel classes of substrates having geometries offering binding strengths almost identical in each step of the process. One of the most striking improvements was seen with ferrocene, in which an iron atom is sandwiched between two parallel rings of CH units. This produced accelerations of 750,000-fold. Improved derivatives of the ferrocene ring molecule led to accelerations of 6 million-fold, and in one case, the reaction favored one of two mirror image isomers in the substrate by a ratio of 65 to 1. Although still not quite up to natural standards, this is a very respectable performance and a tremendous improvement over the earlier experiments.

"The field of synthesis and study of artificial enzymes is in a sense in its infancy," Breslow observes. However, it is already clear that with appropriate molecular design it will be possible to achieve very large rate accelerations, comparable to those typical of enzymatic processes. More exciting, the application of the principles learned from enzymatic reactions permits us to design novel chemical processes that can achieve highly desirable selectivity, of the sort not otherwise achievable outside of biochemistry. The selective accelerated reactions achieved with artificial enzymes that mimic the natural catalysts have the potential to play an important role in chemical synthesis, and such substances may even prove to have therapeutic ability. Thus, one can look forward to continued vigorous growth of this field.

OPIATE PEPTIDES AND RECEPTORS

Of all the preparations on the apothecary's shelf, none holds more fascination than the milky syrup exuded from unripened seedpods of the poppy flower, *Papaver somniferum*. The syrup dries into a brownish sap—raw opium. Although its curative powers are meager, physicians have prescribed it for more than 2,000 years because of its unrivaled pain-relieving ability. Many others crave opium and its natural and synthetic derivatives for the surge of euphoria they induce.

In addition to its ability to produce analgesia and euphoria, opium has well-known side effects. Unlike other medicinal compounds that can be administered in fixed dosage, opium dosage must be increased over time to obtain a constant effect—a phenomenon called tolerance. Addiction also goes hand in hand with physical dependence; opium users are soon unable to discontinue the drug without "withdrawal" symptoms. Drugs with these properties are uniformly addictive, and the laws of all Western nations seek with varying degrees of success to confine their use to legitimate medical need.

The search for addictive free and potent analgesics is a relatively new endeavor, made possible by advances in chemistry in this century. The goals of this research are that severe pain be relieved without clouding and alteration of the mental state and that the phenomenon of tolerance be overcome. The absence of the tolerance phenomenon would allow sustained analgesia to be produced over a long period of time without loss of effectiveness of the analgesic drug.

By 1925, chemists had worked out the exact three-dimensional structure of morphine. It was another 25 years before they could synthesize the correct "stereoisomer" of morphine derived from opium. (Stereoisomer refers to any of a group of isomers in which atoms are linked in the same order but differ in their spatial arrangement.) But thanks to the growing sophistication of synthesis techniques, they were able to produce a large number of opiate analogs. Shortly before World War II, American chemists synthesized an interesting morphine derivative, nalorphine. Although it was a very minor modification of morphine, with the substitution of an allyl group, nalorphine proved to be a powerful opiate antagonist, specifically blocking both the analgesic and the euphoric effects of the true opium "agonists." It proved to be an almost instantaneous antidote for patients at the point of death because of acute morphine or heroin overdose. In 1954, another startling fact was discovered about nalorphine: By itself, it could be almost as potent an analgesic as morphine but

with fewer of morphine's euphoric or addictive properties. Nalorphine is no longer used, either clinically or as an antagonist in the laboratory, because of the introduction of such drugs as naloxone. Naloxone is a pure antagonist without agonist properties of its own. Naloxone has played an important part in the opiate peptide story because its ability to block certain effects has become an important criterion of the opioid (morphinelike) effect.

During the 1960's, it was recognized that the mechanisms by which opiates affect brain functions were similar to those involved in certain hormones (insulin, adrenalin, etc.) and the action of neurotransmitters. All these chemical signals act as intercellular messengers within the brain, central nervous system, and other organs. Because these compounds are effective in low concentrations and act as intercellular messages, it was generally thought they acted at specific receptor sites. Such receptors are usually large, specialized molecules on the outer membrane of the target cells.

Several lines of evidence supported the receptor theory of opiate behavior. First, all opiate agonists show very fundamental similarity in their molecular structure and, like the hormones and transmitters, act (initially, at least) in vanishingly small doses. Second, opiates all exist in left- and right-handed forms. Such alternate architectures are called isomers. This meticulous "stereospecificity" argues strongly for an equally specific receptor molecule capable of recognizing "handedness" in the opiate molecule. A third bit of evidence favoring the receptor theory is that although antagonists like nalorphine are only slightly modified versions of agonists, they work with the same speed and low concentration, suggesting that they may do nothing more than occupy receptor sites, denying access to the opiate agonists.

While these clues favored the receptor theory, they did not constitute proof. This became the major challenge of the 1970's for pharmacologists, biochemists, and molecular biologists, but many difficulties had to be overcome to make any headway at all. One major stumbling block was that biologically active compounds, like the opiates, will fasten to just about any kind of membrane, even in the absence of specific receptors. Such nonspecific binding is a far more frequent occurrence than true receptor binding. One result was obtained by Avram Goldstein and his colleagues at Stanford University School of Medicine. They synthesized radioactively labeled opiates as well as inactive isomers to compare their ability to bind to homogenized brain cell membrane; they found numerous instances of nonspecific binding, of which only about 2 percent of total binding was stereospecific. This meant that the task of isolating the small amount of specific binding from the very large amount of nonspecific binding would be formidable. But the work was the first demonstration of stereospecific, opiate receptor binding, which stimulated the search for better ways of doing it.

Building on the Goldstein technique, in 1973, Candace Pert and Solomon Snyder of the Johns Hopkins University School of Medicine, simultaneously with and independently of similar work by Lars Teranius in Sweden and Eric Bemon at New York University, used a combination of maneuvers to amplify specific receptor binding while suppressing nonspecific binding. "We were able to identify high-affinity binding sites for opiates in fragments of cell membrane from rat brain and guinea pig intestine with the aid of radioactively labeled naloxone, a potent opiate antagonist," Snyder explained. "To investigate the specificity of the binding we compared the ability of the active and inactive optical isomers of the opiates to compete with radioactively labeled molecules of naloxone binding to the receptor. We found that the active isomers of both agonists and antagonists could displace naloxone that was already bound to membrane, and that the pharmacologically inactive isomers had practically no effect on such binding."

In 1975, Snyder, Pert, and Michael Kuhar mapped the distribution of opiate receptors in the brain and spinal cord. They found that receptors are concentrated in the paleospinothalamic pathway, which ascends along the midline of the brain in monkeys and man, and they also found high densities in the amygdala, the corpus striatum, and the hypothalamus, all components of the limbic system, which regulates emotional behavior. This distribution corresponds somewhat to the salient features of opiates—their ability to relieve dull, chronic pain conveyed by the paleospinal pathway (rather than sharp pain conveyed by a second pathway that evolved later) and their ability to induce euphoric states.

Snyder and his colleagues also measured receptor binding in a wide range of animal species. Interestingly, all vertebrates exhibit receptor binding, and there is no detectable evolutionary trend; the most primitive vertebrates like the hagfish and dogfish shark not only exhibit as much receptor binding as monkeys and man, but the receptors of these primitive creatures display virtually the same opiate specificity, indicating that few changes have occurred in chemical structure of receptors over the 400 million years of vertebrate evolution.

This unequivocal demonstration of the universal presence of opiate receptors in all vertebrates posed a deeper question: Why did these sites evolve in vertebrate brains and central nervous systems? It is unlikely they evolved to exploit the analgesic and other properties of an exotic plant indigenous to the Middle East and Orient. If vertebrate brains come equipped with all these highly specific "locks," then in some way they also manufacture equally specific "keys" to fit these locks. The conclusion was inescapable: The normal vertebrate brain must be capable of synthesizing molecules that operate at the same sites as the opiates.

Snyder and his associates suspected that these endogenous agents behave like neurotransmitters. They would therefore act at neuronal synapses, where an axonal fiber of one neuron terminates at a junction on the outer membrane of another neuron. To test this, they homogenized brain cells, fractioned them into different components, and then spun the components in a centrifuge to separate them by specific density. As they surmised, specific receptor binding does indeed occur largely on synaptic membranes. They suggested that the brain's natural opiatelike compounds also bind preferentially to synaptic membranes.

The next step was to identify the brain's natural opiate. John Hughes and Hans Kosterlitz of the University of Aberdeen scored this breakthrough. First, they showed that brain cell extracts could mimic the effects of opiates on smooth muscle tissue. This mimicry was both stereo-

specific and capable of being inhibited by small applications of the antagonist, naloxone, strongly suggesting the presence of a morphinelike factor in the brain extract.

The clincher came in 1975 when Hughes and Kosterlitz succeeded in isolating two nearly identical small peptide molecules from pig brains, each consisting of a chain of five amino acids. They called the factors enkephalins, from the Greek phrase, "in the head." The first four amino acids were identical in each peptide; they differed only in the fifth amino acid. The one terminating with methionine was called met-enkephalin while the other terminating with leucine was called leu-enkephalin.

Once the structure of the enkephalins had been established, the most surprising coincidences occurred. Derek Smyth of the National Institute for Medical Research visited Imperial College and gave a talk on beta-endorphin. Howard Morris, in attendance, was greatly surprised to see that the first five amino acids of this peptide had the sequence of met-enkephalin. Thereafter, Derek Smyth and his colleagues established the so far unknown fact that beta-endorphin had a high affinity for the opiate receptor.

In 1964, Choh Hao Li of the University of California School of Medicine in San Francisco isolated a 91-unit amino acid peptide from camel pituitary gland; he named it beta-lipotropin because its chief function seemed to be the metabolism of fat. However, the metabolizing function was thought to be confined to the first 58 units of the peptide; the role of the last 31 units remained unknown. It was this second group of amino acids in the beta-lipotropin that contained the met-enkephalin sequence. Avram Goldstein of Stanford University obtained samples of beta-lipotropin from Li and found that the 31-unit fragment had powerful opiatelike effects as well.

In 1975, Goldstein and his colleagues identified the first opioid peptides in the pituitary; these included beta-endorphin (before its structure was recognized) and dynorphin, which required 4 more years for partial structure and until 1981 for full structure to be worked out. In 1982, workers in the United States and Japan used the techniques of molecular biology to piece together the RNA nucleotide sequence that specifies large precursor proteins containing the sequences of the endorphins, enkephalins, and most recently, the dynorphins. While these peptides contain common amino acid sequences, they are broken down from different precursor proteins. It appears that these large precursors, ranging in size from 250 to 300 amino acid units, embody the sequences of all brain and pituitary opioid peptides characterized to date, and some of them contain multiple copies of active enkephalins. Evidently, both brain and glandular cells synthesize the large precursor chains, then remove the sequences necessary for their specialized activities.

There is also evidence that enkephalins, endorphins, and dynorphins play an important role in mediating depression, defeat, and other emotions of man and the higher animals. How these peptides interact among themselves and with other peptide hormones and neurotransmitters is a task for the future.

Meantime, what of the longstanding goal of physicians and pharmacologists? Do the brain opiates point the way to the perfect nonaddictive analgesic? Alas, the answer seems to be no. Rats repeatedly injected with enkephalin or beta-endorphin develop tolerance and physical dependence just as they do with morphine, and they also exhibit shaking, diarrhea, and other withdrawal symptoms when the injections are suspended. It appears that analgesia and tolerance are inseparable at this point. The notion that we can become addicted to our own peptides may be discomforting, but at least now we know something we did not know before. As Shakespeare's Cassius observed, "The fault is not in our stars, but in ourselves."

HELPING PLANTS FIGHT DISEASE

When the earth entered a warming period about 10,000 years ago, the great glaciers of the last ice age retreated. As vegetation returned to the land in the temperate latitudes, our ancestors discovered the greatest of all human innovations: the deliberate cultivation of plants to produce food.

Agriculture not only permitted but required the existence of settled communities and populations. It generated the first economic surplus, and this, according to anthropologists and archaeologists, led to the development of urban centers populated by tax collectors, clerics, artisans, and other skilled specialists. It was these latter groups who invented writing, wheels and axles, waterwheels, sailing vessels, and all of the other things necessary for the development of early civilization. As Sylvan Wittwer of Michigan State University put it: "Agriculture is the world's oldest and largest industry and its first and most basic enterprise."

Despite the vast accumulation of agricultural knowledge over 10 millennia, farming today is still afflicted with the same problems that have bedeviled it from the beginning: climate, pests, and disease. Droughts and early frosts, locusts and boll weevils, and diseases caused by a staggering variety of bacteria, fungi, nematodes, viruses, and other pathogenic microorganisms continually threaten the world's growth of food, feed, fiber, and fuel.

Plant diseases are known to extract a sizable annual tax on the world's production and storage of major food crops. Potato blight in Ireland in the mid-1840's led to the starvation of 750,000 people and emigration of 1 million others. An epidemic of brown spot on rice killed millions in the great Bengal famine of 1943. In 1970, an outbreak of southern corn leaf blight, a fungal disease, caused the loss of 700 million bushels of U.S. corn, 15 percent of a feed crop valued at more than $1 billion.

It was commercial plant breeders who saved the day for hybrid corn in the United States. They managed to introduce a totally new cytoplasm, and the sterile male genotype was discarded. The new hybrid retained the features—lack of tassels and uniform height—that facilitated harvesting of the crop, so there was no loss of farm productivity.

Conventional plant breeding is laborious, expensive, and time-consuming, but the crossing and re-crossing of sexually compatible species of economic importance, notably the cereal grains like wheat, rice, and corn, and legumes like peas and soybeans, have contributed mightily to the growth of American agricultural productivity over the past half century. Yet, it is an empirical or "phenomeno-

logical" art more than a science. It lacks an overarching theory or model that relates the great variety of plant processes into a coherent whole. Moreover, plant breeding suffers from severe constraints because it can only be applied to closely related species. Thus, a trait conferring genetic resistance to a given disease in a cereal grain, for example, cannot be bred into one of the legumes.

Plant scientists believe that the great advances in cellular and molecular biology and tissue culture over the past generation, and particularly the development of techniques to recombine and transfer genetic characteristics over the past decade, could provide the key for similar leaps in both understanding and mastery of higher plants important in world food production. The genetic blueprints of plants might be re-engineered in the same direct way that molecular biologists now do with bacteria, using viruses or plasmids as vehicles to transfer entirely new sets of genetic instructions into the chromosomal DNA of the target plant.

For example, one might visualize the isolation and identification of a sequence of genes in Plant X that would confer resistance to a disease. The amplification of this sequence of DNA by cloning into bacteria and the incorporation of the sequence into a suitable vector, would then "infect" embryo cells of the parents of the diseased plant and incorporate this trait in a new kind of hybrid plant. In theory, this direct approach would be far faster and less costly than hit-or-miss crossbreeding.

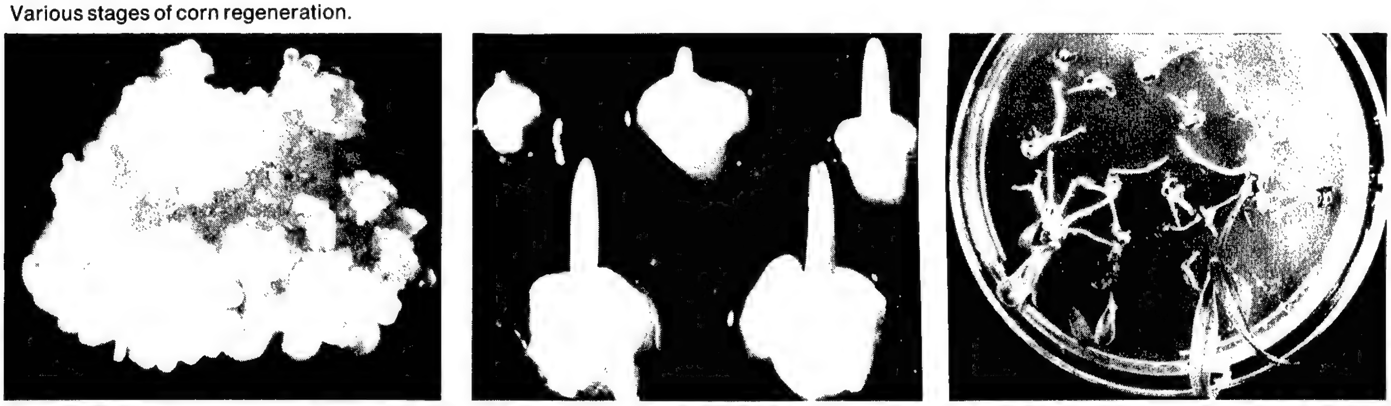
But there are a number of formidable obstacles in duplicating the genetic successes with bacteria in far more complex, higher plant systems. Bacteria are self-sufficient, single-cell organisms, whose DNA is spread out loosely within the cytoplasm of the cell. These organisms belong to the great class called prokaryotes. Although they lack mobility, central nervous systems, and sensory apparatus, higher plants are far more sophisticated and differentiated multicellular organisms. They belong to the second great class of life, the eukaryotes. In them, the cellular DNA is tightly confined within a central nucleus in the cell.

Not only do eukaryotic cells contain far larger amounts of chromosonal DNA than prokaryotes, but this DNA is far more complex in its organization and behavior. Where the DNA of prokaryotes has every triplet of DNA base pairs essential for specifying an amino acid in a protein or some part of a regulatory function, so that all the DNA is critical to the organism, the DNA sequences of eukaryotes are riddled with silent sequences, or "introns," which apparently play no role in specifying the construction of proteins, enzymes, or other structures of the cell, or in controlling cellular activities. Moreover, many of the DNA sequences of eukaryotes jump about within the chromosomes; these are called "transposons." Obviously, sophisticated "editing" takes place after eukaryotic DNA is transcribed into messenger RNA, and before this intermediary sequence is translated into protein. The inability to "edit" introns out of eukaryotic DNA sequences may explain the inability of bacteria to express some sequences of eukaryotic DNA in the form of proteins and enzymes.

Another obstacle is that few plants may be easily regenerated from individual embryonic cells, or even clumps of cells, into whole plants capable of independent growth under field conditions. Unlike unicellular bacteria, plants are highly differentiated, multicellular organisms in which an intricate sequence of control mechanisms must come into play for the individual cells to grow roots, stalk, leaves, and flowers, set seeds, and then enter senescence. A few plants like potatoes, carrots, tobacco, and petunias may be regenerated from single cells, but the cereals and legumes, the world's two most important food groups, stubbornly resist regeneration. Yet, it is essential that this step be mastered to achieve the greatest potential from future genetic experiments.

Plant scientists are beginning to achieve some important advances, however, in regenerating superior cereals and legumes from tissue and cell structures. C. E. Green and Ronald Phillips of the University of Minnesota have broken the "corn barrier" by inducing corn plants to regenerate from a clump of cells (callus). (See figure 7-4.) Both the age and the genotype (genetic strain) of the donor cells, however, are critical. Unfortunately, the callus is not soft and crumbly but hard and compact, so it resists dispersal into individual cells in a suspension culture. Nevertheless, they did find one example of soft callus, stirred it into a

Figure 7-4
Various stages of corn regeneration.



Very young globular stage embryos (mag. 40x)

Mature somatic embryos (mag. 6.6x)

Germination and plant growth

SOURCE: University of Minnesota

suspension culture, and successfully regenerated corn plants from the culture.

Green is optimistic that this work will eventually lead to the ability to clone identical corn plants from single cells. For that, however, one further step is necessary. The tough outer wall of the plant cell must be dissolved by a suitable buffering agent, leaving a protoplast that can be readily penetrated by an enzyme or virus carrying the new genetic instructions to be incorporated into the plant genome.

Edwin T. Bingham of the University of Wisconsin has investigated the problem of why some genotypes of alfalfa will regenerate from culture while others won't. Bingham and a graduate student, Bruce Reisch, found that two dominant genes control the regenerability of alfalfa from callus m suspension culture. This could explain the greater difficulty of regeneration from single cells.

Similar work is proceeding on tomatoes. Cultivated tomatoes do not regenerate well from culture, but a wild strain of Peruvian tomato will regenerate, and David Pratt and Bruce Thomas of the University of California at Davis have crossed the domestic cultivar with a marble-sized Peruvian tomato in hopes of developing a line that would combine the best traits of both species and, at the same time, allow whole plant regeneration from single cells. Maureen Hanson of the University of Virginia has attempted to culture protoplasts of the hybrid culture-tolerant tomato developed by Pratt and Thomas, but she found that conditions, including the nutrient solution in the water supplied the donor plants and the ratio of fluorescent to incandescent light in the growth chamber, must be controlled very precisely.

Although genetic engineering of plants is the long-term goal of basic work on regeneration now under way, a more immediate dividend is the ability to induce and select desirable mutations. If cultures of plant cells are subjected to herbicides and the process repeated with the survivors, highly resistant cells should survive, and these can be tested over several generations to determine whether the trait is stable and heritable. Such an approach might also be possible in searching for plant genotypes resistant to specific diseases. This would bring many efforts to improve plant breeds from the field to the laboratory, sharply telescoping the time and cost of the work. It would be more difficult, however, to adapt such techniques to improve nutritional quality, plant structure, or other features that show up only in adult plants.

Traits exhibited in variant or mutant cells in culture often fail to show up in the regenerated plant. It seems that the mechanism expressing the desired trait is turned off during the growth of the cell into a complete plant. Pratt and Thomas found this phenomenon in the tomatoes that they regenerated from culture. They also found that if the single cells are taken from the regenerated plant and cultured again, the trait will reappear. Apparently, the longer the cells remain in culture, the more variable and unstable they become. Many investigators believe they are seeing the effects of the movable "control elements" first hypothesized more than 30 years ago by Barbara McClintock of the Carnegie Institution, based on her studies of corn. These control elements seem to match the "transposons"—the jumping genes of eukaryotes. They may be more active in the regeneration of plants from cell cultures than when the plant cells become "committed" to organization and differentiation.

Plant scientists are also making slow but steady progress in the identification and use of promising vehicles or "vectors" for delivering foreign DNA sequences into the chromosomal DNA of plant cells. One vector attracting considerable attention is *Agrobacterium tumefaciens*, responsible for crown gall disease in a wide range of broad-leaved plants. The galls are tumors that form in the region of the plant between root and stem. The bacteria enter the plant at the site of a wound or injury, and a ring of tumor-inducing (Ti) plasmids is inserted into the plant cells. A portion of this ring, called T-DNA, becomes incorporated into the plant's chromosomal DNA, subverting its machinery to overproduce opines, a nutrient required by the bacteria.

In theory, the modification of the T-DNA portion of the plasmid using the well-developed techniques for constructing hybrid plasmids and cloning them in *E. coli*, and other bacteria should not present undue difficulty. The plasmids used to induce bacteria to manufacture insulin, human growth hormone and other products are relatively small. When cleaved with an enzyme, restriction endonuclease, they open in only one place, allowing insertion of the foreign sequence of DNA. The Ti plasmid of crown gall, however, is huge, with a molecular weight 95 to 156 million times that of the hydrogen atom. When this is cleaved with restriction endonuclease, it breaks at many different sites instead of a single site. A foreign sequence of DNA can be inserted, but with little hope that a functional plasmid will reassemble.

Fortunately, the active portion of the plasmid, T-DNA, amounts to only about 10 percent of the total. This segment has been re-engineered successfully and cloned in *E. coli*. In one experiment, streptomycin resistance has been transferred successfully into a culture of *A. tumefaciens*, which, in turn, has been used to infect tobacco plants. However, it appears that the gene was not expressed in the plants. Mary-Dell Chilton and her colleagues at Washington University believe it is necessary to splice foreign genes into T-DNA next to a known regulatory sequence, for example, the segment specifying opine synthesis. The regulatory portion of the gene is obviously read correctly by the appropriate polymerase enzymes of the infected plant.

The next step is to infect individual plant embryo cells in culture with the altered Ti plasmid and then attempt to regenerate whole plants from single cells. European investigators have reported some success along these lines. Mark Van Montagu of the State University of Ghent, Belgium, and Jeffrey Schell of the Max Planck Breeding Institute in Cologne transformed plant cells with altered T-DNA. They found one opine-positive cell that regenerated into a plant and retained in its chromosomal genes some of the T-DNA acquired in the culture. Mary-Dell Chilton and her group successfully used *A. rhizogenes* to infect plant roots, and they have regenerated whole plants from the roots. They believe that the T-DNA of *A. rhizogenes*, (Ri), may be an attractive alternative to the Ti plasmid as a broad-range vector.

Mastery of recombinant genetic techniques capable of incorporating desirable new characteristics in plants offers a far greater range of applications than simply helping plants resist herbicides and diseases. Those resistance fac-

tors are likely to be realized first, however, because they are specified by only one or a few genes. Other important properties, such as nitrogen fixation by *rhizobia*, are controlled by as many as 17 genes. It is these proteins that provide the seeds for shoots, roots, and leaves, the sources of most human nutrition.

Although plant breeding and other plant sciences are major research programs in the United States, the number of scientists skilled in the techniques of molecular and cellular biology and genetic engineering is very limited. The problems they must address are enormous in variety and complexity. When Robert Goddard pioneered development of the first liquid-propellant rockets in the United States in the 1920's and 1930's, he found that he had to develop almost single-handedly all of the separate components—tanks, valves, turbopumps, igniters, combustion chambers, nozzles, and inertial control devices. It was not until a "critical mass" of scientists and engineers was mobilized to attack these problems systematically that a practical space propulsion system could be achieved. The situation is much the same in bringing the new techniques of molecular biology and genetic engineering to bear on the age-old problem of improvement of agricultural crops.

While it is not clear how the powerful techniques of molecular biology can be adapted to such complex and sophisticated organisms as plants, it is clear that we will not learn the answers until the community of scientists attacking fundamental questions is large enough to deal with the manifold unknowns.

COGNITIVE DEVELOPMENT IN EARLY CHILDHOOD

Humans "can learn nothing without being taught," wrote Pliny the Elder nearly 2,000 years ago. Pliny was commenting on the helpless nature of infants.

The idea of newborns living in a sea of confusion, distinguishing neither sights nor sounds, has prevailed over the millennia. One problem with this theory is that it has never been proven. Another is that it is not true; ask parents who have watched in wonder as their infant followed an object with its eyes or turned toward the source of a sound.

Over the past 15 years, scientists have begun to document that a newborn can do many things, including process sensory information. Although scientists do not know how vast that bank of infant sensory ability is, a clear picture is emerging of the infant as a highly active, information-processing being.

Researchers are using a relatively new approach—cognitive science—to better understand how much children actually know and how they learn to interact with their environment. Cognitive science focuses on how human beings obtain, store, retrieve, and use information. As researchers begin to dissect the steps taken in the cognitive process, they are finding that cognitive abilities develop much earlier in infancy than had been thought. One reason for the growing awareness of the cognitive competence of young children is a change in the way research is approached. Instead of testing cognitive capacities against tasks they will be able to do when they are older, researchers are now focusing on what youngsters are actually able to do at a given point in their development. Thus, for example, young children are being tested to determine the extent to which they can grasp the concept of enumerating objects by counting them, rather than, as previously, whether they use conventional numbers correctly in counting 5 or 10 objects.

Along with changes in approaches have come new research methods. You can't ask an infant what it can see, but, a method called forced choice preferential looking can help determine it. A display is set up with a stimulus (a striped figure, for example) appearing on the left or on the right. One person holds the infant being tested in front of the display, while an observer sits behind a peephole at the center of the screen and watches the eye and head movements of the baby. Based on those movements, the observer can create an accurate record of what the baby is seeing. Researchers know that 1-month-old babies can see wide-striped patterns, because they consistently stare at them when shown on the display. But the babies' lack of interest when the stimulus is changed to thin stripes indicates that infants cannot see the fine patterns.

Forced choice preferential looking is the equivalent of an infant eye chart. From it, researchers conclude that if infants could read in the first month of life, they could read only the top line of an eye chart. At birth, vision is approximately 20/400; that means that newborns can see clearly at 20 feet what a normal adult can see clearly at 400 feet.

While it was important for scientists to prove what infants could see, it was astonishing to find out how dramatically and rapidly early visual ability improves. By 6 to 9 months, infant acuity is in the range of 20/50. It approaches normal adult values during the second year and possibly even by the end of 1 year, although this is difficult to test because youngsters are not usually motivated enough to be attentive for the long periods of time needed for accurate testing. These findings on sensory development are important to cognitive research because the degree of acuity relates directly to how much information can be stored and ultimately recalled.

Another visual development of great relevance is the ability to see color. Colors are thought to elicit and maintain visual attention and to induce vigilance. They carry information about the physical world and assist in identification, coding, and differentiation of surfaces. Color is often more important than size and shape in determining how readily and accurately we detect and locate stimuli.

Recent testing has shown that an infant's color perception ability exists—but it is weak. At 2 months, infants can make red/white and blue/white discriminations. But they fail in telling yellow and green from white.

The infant eye also fails to make appropriate movements, even though the linkage between visual stimuli—where something is in space—and the motor response—the movement of the eye—seems to be wired genetically. When an infant sees an object on the left, it looks to the left without anyone teaching it to do so. Using infrared video cameras and computerized eye movement measurements, psychologists studying the development of vision have tracked the visual motor control of 4-week-old infants as they follow the movement of an object. Re-

searchers found that infants can visually follow objects but they don't do it particularly well; there is not a smooth match between the velocity of the eye and the velocity of the object, as occurs in an adult. The infants make repetitive 5-degree eye movements in jerky efforts to catch up with the target. Adults, in contrast, make one, large eye movement.

However, newborns are able to make large adultlike eye movements when they look around a dark room without a target to follow. Therefore, it is not clear that the infant eye movement mechanism is immature when it is tracking an object. Perhaps all that is needed is more practice tracking objects, because by 8 weeks of age most infants have begun to refine their eye movements.

The magnitude of the changes taking place in the infant eye's ability to encode information plays a significant role in how visual information is stored and used cognitively. An infant might not be able to remember something it stored at an earlier age, not because it has a memory failure, but because there is a mismatch; the earlier visual encoding may appear different to the more mature visual system.

Normal infants coordinate vision with another sense—hearing—to find things in their environment. Until recently, infant development scales placed the age of head turning toward unseen sound between 4 and 5 months. Observations in clinical practice, however, conflicted with the scientific literature; pediatricians found that newborns turned their heads toward a rattle that was shaken off to one side.

Scientific controls were added to the rattle experiment by taping the rattle sounds and presenting them over a loudspeaker, videotaping the infant's behavior, and having it scored for head turns, vocalizations, and head and body movements by observers who did not know which side the sound came from. The data confirmed clinical observations—1-day-old infants can localize sound. More surprising, the researchers found that newborns also can discriminate different kinds of sounds. They do not like loud noise and generally turn away from it.

These new findings emerged, in part, because of new ways of testing audiovisual abilities. Instead of keeping newborns lying down in a crib, researchers held the babies upright throughout the testing procedure and played the sounds only when the baby appeared to be alert. Also, the rattle sounds were played for as long as 20 seconds—long enough for the infants to hear and locate the source. As with vision, the basic auditory mechanisms are there at birth but are not finely tuned. Infants have difficulty seeing a small spot of light, or hearing a sound of short duration.

So newborns can hear; they have a general mechanism for mapping auditory information. But can they do anything with that stored information? The answer is an unequivocal yes. Researchers have found that newborns can discriminate one vowel from another. When they hear the "ah" sound, their heart rate slows down. The heart rate will return to its normal pace, unless the "ah" sound is switched to a noticeably different vowel. Experiments have shown that subtle vowel changes will again cause the heart rate to slow down. To researchers, this means that, at some level of cognitive awareness, the infants are processing speechlike information about vowel sounds.

Infants, however, do not respond to all sounds. A newborn, for example, will not usually turn to a click, a tapping on the table, or the sound of a train. But a 5-month-old will respond to virtually any sound. These changes in discrimination suggest dramatic brain development that permits an infant's response to a wide variety of stimuli.

One stimulus that attracts infants virtually from birth is the human face. Babies under 3 days old imitate facial gestures and some speechlike behavior. They open their mouths, stick out their tongues, protrude their lips. It is now known that this is not merely random playing; videotapes show that the infants replicate these motions.

The fact that visual preference for faces increases dramatically at about 7 weeks of age—just prior to the time that infants begin to coo and babble—raises the question of the effect of early visual behavior on speech acquisition. What, if anything, do babies learn about speech by watching someone's mouth? As adults, we subconsciously take note of mouth movements when someone is talking. We take this synchronization for granted. But think how unnerving it would be if the two were not aligned, as occasionally happens in a movie.

In one experiment, infants were shown two, side-by-side, filmed images of a talker articulating two different vowel sounds—"a" as in pot and "i" as in peep. A tape of the "a" sound alternating with the "i" sound accompanied the film. Somehow the infants were aware of very subtle, audiovisual differences that made a right and wrong combination of sound and facial movements; they looked significantly longer at the face that matched the sound. They also produced a kind of babbling not usually heard at this age, with rise and fall contours as uttered in a declarative statement.

There are several hypotheses to explain this audiovisual relationship. Either the infants learn this correlation by watching their mother or caretaker, they gather it through their experiences babbling (a recognition of their own sound production lead them to recognize it in others), or they are born with some ability to do it because they are so integrally linked. It is likely that at some level all three hypotheses are involved, but it is still conjecture which holds the lead influence.

Children learn language effortlessly with little dependence on formal instruction. Yet, language is among the more complex strategies to learn; it involves mapping sounds and meanings in a systematic way. Since humans are the only animals with language, it is possible that much—some argue even all—of the ability to learn language is innate. This has been debated for 30 years without much resolution. But recent research on how children learn language has shown that something very special is indeed involved.

Consider the "language" system devised by deaf children who have not been taught sign language. Researchers videotaped them "talking" with their mothers and found that the youngsters had spontaneously developed a gestural communication system. The children used nounlike signs, usually a pointing gesture, to refer to people, places, and things. Verblike or adjectivelike signs, often done in pantomime, referred to actions and attributes: chewing symbolized the verb "to eat"; drawing a circle in the air with the index finger meant "round." The youngsters added markers to modulate sentence meanings, nodding the head "yes" or shaking it from side to side to indicate "no."

By moving from one sign to another, the children linked their thoughts and expressed them in gestures. Syntactically they tended to put the object before action—for example, pointing to an apple and then making a gesture for eat. Children with hearing use a different syntax when they develop early language, tending to put action before object. For the researchers, this illustrates that gesture language in deaf children is not merely English pouring out through their hands. It is viewed as a self-generated language with its own fundamental linguistic properties.

Research on mentally retarded children provides another example of language-specific learning mechanisms. The youngsters studied had low IQ scores—44 to 56. Yet, they could string together an impressive sentence with fairly correct relationships between phrases, clauses, and proper endings of words—linking plural verbs with plural nouns, for example. Semantically their vocabulary was severely limited, or words were used incorrectly, because of their low intelligence. That they were retarded in every area but one—language structure—provides strong evidence that at least some aspect of language can develop autonomously from cognition.

Whether normal language acquisition develops on its own or as a part of other cognitive abilities, its beginnings are rooted deep in infancy and evolve slowly over time. The ability to understand words apparently begins between 9 and 12 months of age. Producing a few recognizable words begins around the first year of life. Combining words into two-word sentences takes place in the middle of the second year for most children.

Although there are general milestones that children usually pass, the stages of development of language are not well understood. Specialists involved in early childhood language are not even sure what vocalizations make up language. When babies babble, are they mapping out the terrain as in a language, or are they uttering random sounds?

Babbling was long thought of as prelinguistic vocal behavior characterized by random phonetic output unrelated to later development. But recent research illustrates that there is a continuity. Using audio and video tapes, parental daily logs, and computerized data analysis, the articulations of a group of babies were studied from their earliest babbling to the development of words at around 15 months.

Researchers found that although babbling sounds are meaningless in relation to the situation in which they are uttered, the sounds are not random. Children show a preference to use certain vowels or gutteral sounds when babbling. As they discover that names stand for categories and begin to make up words, children choose pretend words (or proto-words) that stand in between babble and real words. Proto-words are related to babble because they are phonetically linked to it; they are based on the vowel or consonant that the child has favored in babble talk. But proto-words are related to real words too, because both are used systematically to refer to specific objects.

Children must know how to categorize before they talk, because language development depends on the ability to categorize perceptual inputs. But young children have their own special way of categorizing. They tend to take a stereotypical view. A bird is a robin—not a penguin. All animals are kitties. Curiously, they know what to put in their broad categories. A car, for example, could never be a kitty, but a tiger could be. As time goes on, the child's map becomes more differentiated, and at some point, a tiger could never be called a kitty. Researchers are beginning to understand better how this differentiation takes place. A group of 4-year-old children was studied over the course of a year. At each research session, they were asked to give names to certain toys in the room. As the year went on, each child's categories—and vocabulary—grew.

How did this happen? Contrary to popular belief, the researchers found that mothers do not automatically correct their children's speech and tell them the proper adult word to use. Mothers tend to correct only those errors that they consider to be wrong from the child's perspective—such as calling a house a doggie. The youngsters can readily accept such a correction because it fits in with their way of thinking.

But moving forward linguistically and cognitively is not as easy. Mothers can correct their children's words—telling them that the round object they call a ball is, in fact, a bank. Children will continue to call it a ball until their mothers show them—or until they discover for themselves—that there is a slot to put money in. When children become aware that the round object doesn't function as a ball, they will be able to accept the adult word for it—bank. Sometimes, children will use a combination word—ball-bank—to indicate an awareness of the relationship between two categories until the separation is complete.

In other words, children have their own linguistic agenda. Parents can guide but not dictate when and how it will unfold. Developing the linguistic concept of causality provides a good example of this. Psychologists have said that children do not have the ability for causal thinking until they are 7 or 8 years old, when they can see a sequential relation between two physical events. But language specialists have noticed that children as young as 2 and 3 make causal statements that are linguistically and conceptually different from using causitive verbs such as "get," as in "I get dirty."

Children hear many cues in their environment for causal thinking. "The dog is barking because he wants to go out," or "The baby is crying because she is wet." But researchers have found that when children make causal statements, they are not repeating what adults have said: The statements are conceptually devised by the children. "I want a cookie" becomes "I want a cookie because I am hungry."

The causality expressed by 2- and 3-year-olds is commonsense; it deals with the child's own feelings. Although this may suggest that the causal sentences of the youngsters are ego-centered, the phenomenon is somewhat more complex than that. By making their causal statements, the children are learning to take into account the activities of people other than themselves. And when asking "Why?," a question that can elicit a causal response, they learn to take the listener's intentions into account and differentiate it from their own interpretations. This decentering is considered to be a major aspect of language and cognitive development.

Researchers have recently observed that even 2-year-olds can understand the principle of physical causality. In an experiment, children were shown a cause-and-effect sequence—the turning on of a blower, which then puts out

a candle. The children were shown two potential causative agents. One blower had its open side facing a lit candle; the other did not. In the past, psychologists said that children could not understand the causal mechanisms involved and choose the correct answer. But in this experiment, the children systematically chose the blower whose opening faced the candle.

Young children have some competence in comprehending physical causality, but that does not mean they have a complete understanding of it. They might have an implicit understanding of causality as a rule that guides the way they interact with their environment, but they might lack the explicit or metacognitive knowledge of its principles.

As children get older, their intuitive cognitive abilities become more sophisticated. Categorizing is a good example. Initially, natural categories of objects, such as boats, resemble one another in the child's mind. But, young children, unlike older children and adults, find it difficult, and at times impossible, to form categories of diverse objects by isolating a property they have in common. It may be beyond young children to put a boat and a sponge together because both float.

Changes in the way youngsters make categories have been charted in a group of elementary school children ranging from kindergarten to fifth grade. In a test using cards of varying sizes and shades of gray, children were shown three cards from a pack; two of the cards were identical in size but very different in shade (light gray and dark gray). The third card was close but not identical in size, and close but not identical in shade, to the dark gray card.

When asked which two cards went together, the kindergarten children uniformly picked the two that were similar overall but which were not identical in any way. Fifth graders selected the two cards that shared one identical component. Data on the second graders were ambiguous; they were in transition between the holistic and analytical categorization strategies.

Why do youngsters make such cognitive shifts? Perhaps there is a natural predisposition to deal with wholes first and switch to abstract properties later—a grouping strategy that may better prepare children to deal with complex concepts.

By observing how children solve problems, researchers are also getting a better understanding of the wide range of strategies that are used, and how cognitive abilities at one stage of development relate to earlier abilities and to those still to come. They have found that children learn about problem solving without direct instruction. In an intriguing experiment, youngsters 3 to 6 were asked to move one set of inverted cans, each can of a different size and color, onto pegs so that they matched the arrangement of another identical set of cans. The rules were simple: only one object could be moved at a time, and a small can could not be placed on a larger one. The children instinctively developed a variety of strategies to move the cans. On a cognitive level, the youngsters showed the same rich repertoire of problem solving skills used by adults—means-end analysis, search, evaluation, planning—but in rudimentary forms.

Ability to work with numbers is attracting much attention in cognitive research because it appears to represent a uniquely human cognitive ability. Perhaps it is even innate; babies at 6 months can tell a difference between two and three objects when different sets are flashed on a screen.

Traditional learning theory says that young children are not supposed to be able to count because they fail to comprehend the concept of conservation, or constancy, of numbers: that eight eggs in eight cups will still total eight when they are taken out of the cups and placed in a pile. But, as children learn complex rules of language structure by themselves, they also learn to count without the benefit of formal instruction. By age 3, preschoolers understand the concepts of addition and subtraction, see the difference between more and less, and can carry out simple mathematical reasoning.

In the "magic experiment," children are shown two plates—one with two plastic toys and the other with three. They are told that the plate with fewer toys is the "loser" and that the one with more toys is the "winner." When the toys are switched around or spread out on a plate, children as young as 3 are still able to identify the "winner" and "loser," even though 3-year-olds are expected to fail at conservation tasks.

Even more impressive is evidence that children as young as 2 years old can count even though they do not do it the way adults do. In general, they tend to use number words differently than adults do, although they use them consistently. One child might always count the objects in the following way: one, six, nineteen, seven. However, that child will always use the word "nineteen" to refer to the third item in a set. These idiosyncratic errors in counting, which are similar to such errors as "I runned" made by young language learners, show that the child's use of language and numbers is rule governed. As they get older, most children correct their own language and counting errors as they develop increasingly complex cognitive skills.

Through the magic experiment and others like it, a picture of the capacity of young children to use numbers competently has begun to emerge. As research in early childhood cognition continues to probe the nature of the young mind, it is likely that other cognitive abilities that were previously thought to be "adult" will also fall in the child's domain.

The perceptual and cognitive capacities of young children as they develop are becoming much better understood through research. The knowledge gained will serve as a basis for improving the processes of early childhood education. By knowing more about sensory and cognitive development, educators will be able to design better learning programs for normal children as well as for those with handicaps.

EXPLORING THE OCEAN FLOOR

The last great frontier on the planet is the ocean floor, a lightless, long-inaccessible realm at great depth and pressure composing 70 percent of the earth's surface.

As recently as 25 years ago, scientists had only the sketchiest knowledge about this vast *terra incognita*. By means of survey cruises and soundings, they had learned something about the topography, age, and composition of the seafloor. They knew that the ocean is seamed by ridges

and troughs and that the oceanic crust is composed of volcanic basalt. They sensed that processes were at work on and beneath the seafloor of an entirely different order than those found on continental land masses, but could only conjecture about their nature. Knowledge of these processes might settle longstanding controversies troubling many established disciplines.

Consider the problems presented by paleontological discoveries. The fauna of today's widely separated continents is highly distinctive—marsupials but no indigenous mammals in Australia, lions and leopards in Africa, jaguars and ocelots in South America, cougars and bobcats in North America. Yet paleontologists found increasing evidence in the fossil record that identical faunal species roamed the continents in the remote past, indicating that the continents must have been connected in earlier times.

This was not a new idea; the uncanny fit of certain continental margins, notably Africa and South America, led cartographers and others to suggest this possibility as early as the 17th century. In 1911, Alfred Wegener, a German meteorologist, advanced the hypothesis of continental drift to explain the fossil and other evidence, but geologists stoutly resisted the idea. They saw no way the lighter sediments and granites of the continents could plow through the dense basalt of the oceanic crust.

A provisional solution to the problem was the hypothetical land bridge between distant continents. The land bridge allowed the interchange of faunal species in ancient times. Later the bridges conveniently subsided beneath the sea. This scheme could account for present faunal diversity, and it had the virtue that it squared with the prevailing notion among geologists that the earth's topography is shaped primarily by uplift and subsidence. Although some conjectured that the Mid-Atlantic Ridge might be a remnant of the land bridge linking the Old World and the New World, there was really no hard evidence for any of these hypothetical structures.

In the early 1960's, several earth scientists proposed a seafloor spreading model that offered a way out of the impasse. They suggested that both the continents and the oceanic crust literally float on the viscous, semimolton upper mantle of the earth. The midocean ridges are zones at which magma from deep inside the mantle pushes up through the crust, separates, and hardens to form new crust; deep trenches delineate active margins, or zones where crust is *subducting* or plunging back down into the mantle to be recycled. Later, this basic model was refined into the *plate tectonics* theory, which describes the history and dynamics of the earth's crust in terms of a number of plates that were constantly shifting over the earth's surface and, in the process, breaking up and reassembling continents, building mountains, and opening and closing ocean basins.

The plate tectonics concept unifies volcanic, seismic, geologic, paleontologic, and other diverse phenomena into a comprehensive, dynamic whole. It could, for example, explain the curvilinear chains of active volcanoes and the belts of intense seismic activity that make up the famous Ring of Fire rimming the Pacific Basin. Research in the deep oceans has helped refine and advance the plate tectonics theory. Measurements of magnetism over the midocean ridges showed that there were stripes of normal and reversed polarity arranged symmetrically on either side of the ridge. The pattern corresponded to that observed on land, suggesting that as the basaltic lava intruded at the spreading center, cooled, and solidified, it also registered the prevailing orientation of the earth's magnetic field. The symmetrical matching of the stripes on either side of the ridge crest could be explained as representing greater age at progressively greater distances from the ridge axis. For most geologists, this was proof that the midocean ridges represent spreading boundaries where two great plates are separating over time.

Many questions about the detailed workings of the plate tectonic process remained unclear, however. What happens to sediments on top of a subducting plate? Are they scraped off and piled up against the landward plate, or are they carried downward into the mantle on the descending plate? Are there circumstances in which oceanic crust might push on top of the continental plate margin? What role, if any, does plate tectonics play in concentrating metallic elements into ore deposits of commercial interest?

It was clear that the answers to these and many other questions might be found on and beneath the ocean floor and that a new and more powerful array of instruments and facilities would be essential if oceanographers were to conduct both direct and indirect probes of the ocean floor and its underlying structure. Deep-diving submersibles like *Alvin* were pressed into oceanographic research service to permit a three-man crew (a pilot and two scientists) to reach depths of more than 2 miles, allowing scientists to photograph seafloor structures and biota, obtain samples, deploy instruments on the seafloor, and obtain other data by means of shipboard instruments. Side-looking sonar was developed to map seafloor topography at high resolution, and seismic profiling techniques used in oil exploration were adapted for use on the sea bottom to delineate the layering of subsurface structure. Magnetic, gravimetric, thermal, and conductivity measurements also could provide a wealth of other geophysical information bearing on the subsurface structure of the oceanic basement crust and sediments.

Up until the 1970's, little evidence existed of high-temperature, hydrothermal circulation in the ocean crust, even though most models of heat flow through oceanic crust postulated extensive high-temperature, hydrothermal circulation and hot springs at least along midocean rifts. The first evidence for such activity was the recovery of widespread iron-manganese-rich sediments immediately overlying the oceanic basalt. Evidence from heat flow data obtained at ridge crests indicated that a major proportion of the heat associated with the formation of new oceanic crust must be removed by convection. In the mid 1970's, high temperature anomalies were discovered in bottom waters over the Galapagos spreading center. And subsequent submersible dives using *Alvin* in the same area discovered active hydrothermal hot springs. (See figure 7-5.) These and other discoveries implied that hydrothermal circulation and activity are integral parts of seafloor spreading.

So far, six regions with many active hydrothermal vent sites—hot springs on the ocean floor—have been found in the Pacific, four of them on the fast-spreading East Pacific Rise, as well as on the Galapagos Rift and in the Guaymas Basin. These sites have clusters of mineralized sulfide mounds

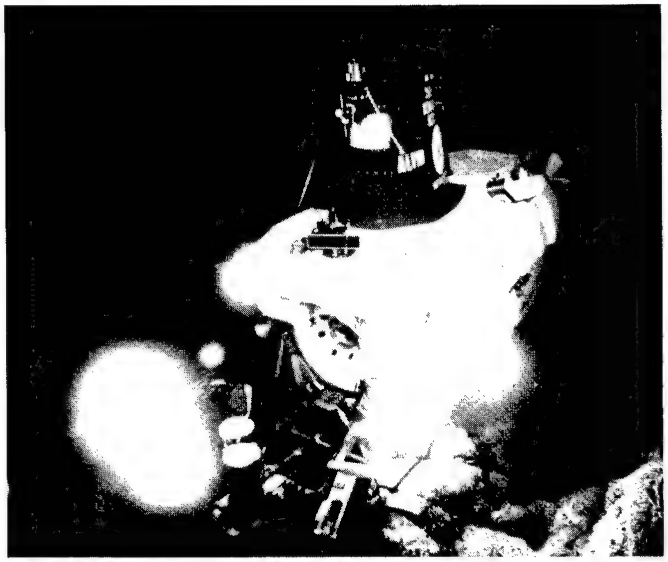


Figure 7-5
Oceanographers in the *ALVIN* looking at hydrothermal vents.

SOURCE: Woods Hole Oceanographic Institution

or chimneys spewing out very hot (350°C) sulfide-rich seawater. Because the newly formed crust along the narrow ridge axis is heavily fractured, the seawater at a pressure of 200 to 300 atmospheres seeps down into the crust to a depth of several kilometers, leaching and exchanging elements with the surrounding rocks on the way, picking up heat and possibly other elements from the underlying magma body, and then is expelled along with its cargo onto the ocean floor, where it mixes with ambient sea water and precipitates various mineral sulfides. This energetic type of hydrothermal spring, called a *black smoker*, indicates that they are sites of actively forming sulfide mineral deposits of the type existing in ancient oceanic crustal slabs found embedded in continental rocks.

A second, lower temperature type of spring is usually found near the black smokers. It emits lukewarm water (20°C) from hairline cracks in the pillow lava of the rise crest and does not build sulfide mounds. These gentler springs are fascinating for entirely different reasons than the black smokers: they are densely populated by an exotic biota—tube worms, crabs, clams, and other mollusks. The predatory crabs survive by eating the bivalves, but how do the other organisms survive? No light reaches these great depths, so that photosynthesis— the basis of all previously known life on this planet—cannot play a role. It turns out that several types of bacteria capable of extracting energy by oxidizing sulfides to sulfates abound near the vents. The filter-feeding clams and other mollusks dine upon these bacteria.

But how do the tube worms manage? They lack mouth, gut, and anus; while they possess bright red flowerlike petals or plumes at one end to absorb oxygen and carbon dioxide, what is their food?

Biologists have determined that the sulfide-rich water is their food. Tube worms (see figure 7-6) are inhabited by dense colonies of bacteria capable of oxidizing sulfide to sulfate and using the energy liberated by this process to reduce carbon dioxide. The reduced carbon dioxide is then incorporated into bacterial protoplasm which ultimately is used by the tube worms. In return for this service, the tube worm takes in oxygen and carbon dioxide through its red plumes and circulates it through its blood system to the bacteria colonizing it, and it also provides an optimum environment for its tiny bacterial partners to do their work. Bizarre as this arrangement may seem, it works beautifully. Tube worms of a length of 2 to 3 meters have been found.

The most exotic of these seafloor hot springs was discovered in 1980 in the Gulf of California off Guaymas, Mexico. The hot water vents, in addition to building up pagodalike sulfide chimneys, also form hydrocarbons in the surrounding sediments and crack them into a variety of fractions, including gasoline-range hydrocarbons. The process that produces and cracks the oil operates at much higher temperature than the gentler but more sustained processes that create major deposits of petroleum having commercial importance. The critical factor here is the very rapid rate of sedimentation in the Gulf of California, about one meter per thousand years; sedimentation proceeds much more slowly at spreading centers far from land.

Even more remarkable is the discovery in the Gulf of California of vents of huge orange, yellow, and white mats of bacteria plastered directly against the pagodalike chimneys, apparently basking in water superheated to 300°C. This is far above the temperature tolerance of all known bacteria, some of which can flourish inside of hot springs and geysers on land. Biologists suspect that the ability to withstand these temperatures is related to the fact that, even at these high temperatures, seawater cannot boil at depths of 2 to 3 kilometers, where water pressure ranges from 250 to 300 times that of the atmosphere at sea level. Another interesting feature of the bacteria is their size;

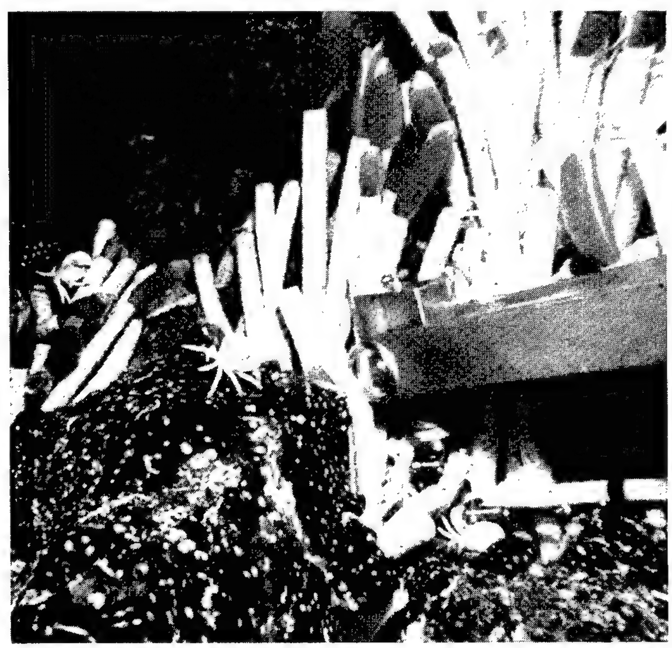


Figure 7-6
Robust communities of tube worms.

SOURCE: Woods Hole Oceanographic Institution

Table 7-5. Top twenty funded oceanographic institutions: FY 1982

Institutions	Total marine sciences budget	Federally funded
University of California, San Diego	$62,665	$50,615
Woods Hole Oceanographic Institution	40,500	32,531
Columbia University (Lamont-Doherty Geological Observatory)	16,850	12,300
University of Miami	15,590	9,749
University of Rhode Island	14,024	9,761
University of Hawaii	12,490	7,837
Oregon State University	12,000	8,510
University of Alaska	10,210	6,278
University of Washington	10,047	9,043
University of Delaware	9,500	6,000
Texas A & M University	7,422	5,360
University of Southern California	4,624	2,997
University of California, Santa Barbara	4,210	2,887
Duke University	3,456	2,029
University of Georgia—Skidaway	2,579	1,426
University of Texas, Port Aransas	2,315	365
SUNY, Stony Brook	2,078	1,453
University of South Carolina	1,969	1,874
San Jose State (Moss Landing)	1,814	975
Bigelow Laboratory	1,620	1,598

SOURCE: National Science Foundation, Directorate for Astronomical, Atmospheric, Earth, and Ocean Sciences, unpublished data.

Science Indicators—1982

some individual cells are large enough to be seen by the unaided eye.

Recent discoveries made with *Alvin*, though spectacular, are but the latest results of more than two decades of research on the ocean floor. During the past two decades, advances in our understanding of the ocean floor have depended heavily on advances in deepsea drilling techniques, on the development of ancillary instruments for locating and mapping promising drill sites, on the availability of sensitive laboratory instruments for analyzing the cores of sediments brought up from the ocean floor, and, of course, on institutions where scientists can analyze and coordinate information obtained from these diverse techniques. (See table 7-5.)

Ocean geologists often liken drillships to telescopes or particle accelerators: they are tools of the trade, necessary for gathering raw data for later detailed analysis. As the raw data obtained with these tools leads to a better understanding of the nature of the system investigated—be it the ocean floor, the distant universe, or the microscopic structure of matter—the need for more refined tools to obtain more refined data grows apace. In the earliest years of scientific ocean drilling, the technique was a novelty. Any core at all that could be extracted from the ocean floor was bound to contain interesting data, as, in the early 17th century, any telescope discovery was bound to reveal something new, and in the 1950's and 1960's, accelerators produced new hadrons in profusion. Thus, even one decade ago, ocean going geologists were concerned primarily with sampling different regions of the ocean basins.

The initial exploratory stage was followed by the development of increasingly powerful drilling techniques and refinements in criteria for site selection. Drill strings were developed to function in water of ever-increasing depth and to penetrate ever deeper into the ocean floor. The hydraulic piston corer, capable of extracting samples hundreds of meters long without disturbing sedimentary layers, was perfected. At the same time, the capabilities of seismic profiling instruments to provide precise prior survey information about appropriate drill sites grew apace. Most recently, success has been achieved in relocating old drill holes and placing seismic and thermal measuring devices within them to monitor continuously processes occurring deep within the ocean crust. The *Glomar Challenger* has been the mainstay of the U.S. Deep Sea Drilling Program for the past two decades. During this period, the vessel has made more than 80 cruises and drilled more than 600 holes into the floors of most of the world's oceans. Initially a strictly U.S. venture, the program now draws financial support and participating scientists from France, Germany, Japan, and Great Britain as well as the United States.

Ocean floor drilling with the *Glomar Challenger* has established, along with paleomagnetics, the age structure of the ocean crust and has provided indisputable confirmation of the seafloor spreading hypothesis. Chemical analyses of oceanic basalts indicate a wide range in elemental composition. This, along with geophysical measurements, suggests that the mantle, the source of these basalts, is also highly variable and heterogeneous in composition.

Recent interest in seafloor drilling has focused on the spreading centers and on plate margins. Active margins, which occur when two tectonic plates collide, are among the most geologically active regions on earth and, therefore, are of great interest to scientists from many disciplines. While the *Glomar Challenger* has drilled into active margins and provided direct evidence for subduction accretion only along the Middle America trench, the results of these explorations are intriguing. Unanticipated evidence for sediment subduction, for subcrustal erosion associated with subduction, and for large vertical motion on the order of kilometers of subsidence has emerged. Future multidisciplinary investigations along active margins hold considerable promise for advances in scientific understanding as well as for yielding information to assess the economic significance of the margins. The large uplift and subsidence occurring at some of these margins have significance for the development of hydrocarbon reservoirs. Likewise, the large amounts of sediments that are subducted at the margins may have geochemical implications related to the genesis and deposition of other useful minerals.

Recent advances in technology have significantly increased the capability of the Deep Sea Drilling Program to provide precise, refined scientific information. Two such advances are worth noting explicitly.

First, an hydraulic piston corer (HPC) that can, in optimum circumstances, drill into the ocean floor and recover intact cores consisting of the upper few hundred meters of sediments has been developed. By preserving the original sedimentary records, the HPC permits high-resolution studies of the youngest deposits on the ocean floor. For example, scientists are now able to study sedimentary cycles that repeat themselves on the order of every 20,000, 40,000, and 100,000 years and are related to the earth's orbital variations. These orbital variations, along with continental drift, seafloor spreading, and sealevel changes, are thought to be the major mechanisms that control present and past climates. However, the climatic history of the earth can only be studied in sufficiently fine detail by using intact, undisturbed HPC cores in which oxygen isotope variations, biostratigraphy, and detailed magnetic stratigraphy can be correlated on a millimeter to centimeter scale.

Of special interest to many earth historians has been the discovery that cores recovered from the ocean floor contain the same so-called iridium anomaly at the Cretaceous-Tertiary boundary laid down 65 million years ago. This same anomaly has been noted in continental sediments of this age. The abrupt jump of iridium abundance at that boundary, as well as jumps in the abundances of certain other heavy elements to levels thus far found only in meteorites, suggests to some scientists that the earth suffered a collision with a comet or small (10-15 kilometers in diameter) asteroid at this time, and the event may have been associated in some way with the mass extinctions of marine and land life that came at the end of the Cretaceous period.

A second technological advance worthy of special mention has been the development of a capability for relocating and re-entering earlier drill holes. By means of this capability, the *Glomar Challenger* was able to reach a drill depth of 1,350 meters early in 1982, including 1,075 meters in the hard crystalline rocks of the oceanic crust underlying the top 275 meters of sediment. The operation was conducted in the Panama Basin at a water depth of 3,470 meters, resulting in a drill string length of more than 4.8 kilometers.

Hole 504B, the official tag for the Panama Basin project, did far more than set a record for the *Glomar Challenger*. For example, it confirmed that mineralization is a byproduct of the production of new crust at the spreading margins. Additionally, it went a long way toward confirming the supposition that certain mineral-rich rocks, called ophiolites, found in Cyprus and elsewhere, are massive slabs of oceanic crust that have been shoved up onto continental plate margins instead of being subducted into a deep ocean trench. What makes this important is that massive sulfide ore bodies are often found in these beached slabs of oceanic crust. (The copper-rich deposits on Cyprus were among the first to be mined in the Bronze Age.)

The flow of important discoveries touched upon here testifies to the vigor of present oceanographic research utilizing the wide array of tools that have rendered the ocean floor far more accessible. But tools wear out. After 15 years of valiant service, the *Glomar Challenger* is scheduled to end its scientific drilling career at the end of 1983. It is to be replaced by a more modern drilling platform or a large vessel, probably a leased commercial drill ship. Plans call for such a vessel to operate at higher latitudes and in worse weather, remain at sea longer, provide more laboratory space, and, not least, handle a drill string much longer than the *Glomar Challenger*.

If, as historians tell us, the past is prologue to the future, the investment in ocean drilling, new research vessels, and both manned and unmanned submersible craft and equipment will yield as much new knowledge about the processes of the ocean floor in the next 25 years as they have in the past 25 years.

Appendix I
Statistical Tables

Appendix table 1-1. National expenditures for research and development[1]: 1969 and 1979

(Dollars in billions)

Country	1969	1979
France	$ 2.7	$11.0
West Germany	3.1	20.9
Japan	3.0	19.3
United Kingdom[2]	2.5	7.1
United States	25.6	55.0
U.S.S.R.[3]	31.8	88.5

[1] Gross expenditures for performance of R&D including associated capital expenditures except for the United States where total capital expenditure data are not available.

[2] U.K. expenditures are for 1978/79.

[3] Estimates of U.S. dollar values of Soviet R&D expenditures were provided in Robert W. Campbell, *Soviet R&D Statistics 1975-1982,* National Science Foundation, 1983, pp. 28-39. There are difficulties in making ruble-dollar conversions and therefore these estimates are only approximate figures.

SOURCES: France: Délégation Générale à la Recherche Scientifique et Technique, unpublished statistics.
Japan: Scientific Counselor, Embassy of Japan, Washington, D.C., unpublished statistics.
United Kingdom: Cabinet Office, The Central Statistical Office, London, unpublished statistics.
West Germany: Bundesministerium für Forschung und Technologie, unpublished statistics.
United States: National Science Foundation, *National Patterns of Science and Technology Resources, 1983,* in press.
U.S.S.R.: Robert W. Campbell, *Reference Source on Soviet R&D Statistics, 1950-1978,* National Science Foundation, 1978, and Robert W. Campbell, *Soviet R&D Statistics 1975-1982,* National Science Foundation, 1983.

See figure 1-1.

Science Indicators—1982

Appendix table 1-2. Average annual rates of increase[1] in national R&D expenditures: 1963-79

Country	Period I	Percent	Period II	Percent	Period III	Percent
United States	1964-70	1.7	1970-73	0.5	1973-79	2.0
Japan	1963-69	13.9	1969-73	11.6	1973-79	5.9
West Germany	NA	NA	1969-73	8.0	1973-79	3.9
France	1963-69	9.9	1969-73	2.2	1973-79	3.4
United Kingdom	1964-69	2.4	1969-72	.1	1972-78	2.9

[1] At 1975 prices.

NA = Not available.

SOURCE: Organisation for Economic Co-operation and Development, *OECD Science and Technology Indicators I, Volume B: Basic Statistical Series* (Paris, 1982), p. 20.

Science Indicators—1982

Appendix table 1-3. Scientists and engineers[1] engaged in R & D per labor force population, by country: 1965–82

Country	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	Scientists and engineers[1] engaged in R & D per 10,000 labor force population																	
France	21.0	23.3	25.3	26.4	27.2	27.3	27.8	28.1	28.4	28.8	29.3	29.9	30.0	31.0	31.6	NA	NA	NA
West Germany	22.7	22.4	24.9	26.2	28.4	30.9	33.8	36.0	37.8	39.1	41.0	41.7	44.3	NA	47.7	NA	NA	NA
Japan	24.6	26.4	27.8	31.2	30.8	33.4	37.5	38.1	42.5	44.9	47.9	48.4	49.9	49.4	50.4	53.6	55.6	NA
United Kingdom	19.6	NA	NA	20.8	NA	NA	NA	30.4	NA	NA	31.2	NA	NA	33.2	NA	NA	NA	NA
United States	64.1	66.1	66.1	66.9	65.9	63.6	60.4	57.9	56.5	55.8	55.5	55.5	56.4	56.9	57.9	60.8	62.4	63.8
U.S.S.R. (lowest)	44.8	47.1	50.7	53.5	56.5	58.4	63.0	66.5	71.2	74.5	78.2	79.8	81.0	82.8	84.4	86.3	89.4	89.8
U.S.S.R. (highest)	48.2	51.4	55.3	58.8	62.1	64.2	69.1	73.2	79.2	82.9	87.5	89.4	91.1	93.4	95.5	98.0	101.4	102.4
	Scientists and engineers engaged in R & D (in thousands)																	
France	42.8	47.9	52.4	54.7	57.2	58.5	60.1	61.2	62.7	64.1	65.3	67.0	68.0	70.9	72.9	NA	NA	NA
West Germany	61.0	60.0	64.5	68.0	74.9	82.5	90.2	96.0	101.0	102.5	103.9	104.5	111.0	NA	122.0	NA	NA	NA
Japan	117.6	128.9	138.7	157.6	157.1	172.0	194.3	198.1	226.6	238.2	255.2	260.2	272.0	273.1	281.9	302.6	317.5	NA
United Kingdom	49.9	NA	NA	52.8	NA	NA	NA	76.7	NA	NA	80.5	NA	NA	87.7	NA	NA	NA	NA
United States	494.5	521.1	534.4	550.4	555.2	546.5	526.4	518.3	518.3	525.1	532.7	546.3	570.4	594.2	620.2	663.4	691.4	716.9
U.S.S.R. (lowest)	521.8	556.5	607.8	650.8	698.8	733.3	804.0	862.5	937.0	995.8	1,061.8	1,100.5	1,135.4	1,177.4	1,216.4	1,271.2	1,320.4	1,340.4
U.S.S.R. (highest)	561.4	607.6	662.6	715.2	767.5	806.8	881.6	950.1	1,042.4	1,108.0	1,187.6	1,233.7	1,276.8	1,328.0	1,377.4	1,442.4	1,497.9	1,340.4
	Total labor force (in thousands)																	
France	20,381	20,522	20,676	20,744	20,996	21,465	21,638	21,817	22,083	22,282	22,310	22,440	22,697	22,894	23,059	NA	NA	NA
West Germany	26,887	26,801	25,950	25,968	26,356	26,668	26,725	26,655	26,712	26,215	25,323	25,088	25,044	25,230	25,573	25,833	25,680	NA
Japan	47,870	48,910	49,830	50,610	50,980	51,530	51,860	51,940	53,260	53,100	53,230	53,780	54,520	55,320	55,960	56,500	57,070	NA
United Kingdom	25,498	25,632	25,490	25,378	25,375	25,308	25,123	25,195	25,547	25,601	25,798	26,097	26,282	26,407	26,464	26,380	26,106	NA
United States	77,178	78,893	80,793	82,272	84,240	85,959	87,198	89,483	91,755	94,178	95,955	98,302	101,142	104,368	107,050	109,042	110,812	112,383
U.S.S.R.	116,494	118,138	119,893	121,716	123,584	125,612	127,672	129,722	131,610	133,600	135,767	137,987	140,140	142,214	144,201	146,068	147,753	149,215

[1]Includes all scientists and engineers engaged in R & D on a full-time-equivalent basis (except for Japan whose data include persons primarily employed in R & D excluding social scientists, and the United Kingdom whose data include only the Government and industry sectors).

NA = Not available.

NOTE: Estimates are shown for most countries for latest years and for the United States for 1966 and 1967. A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

SOURCES: Organisation for Economic Co-operation and Development, *Labor Force Statistics, 1965–1976* (Paris, 1978), p. 23; Quarterly Supplement; Council of Economic Advisors, *Economic Report of the President,* 1983, p. 196.

France: Délégation Générale à la Recherche Scientifique et Technique, unpublished statistics.
Japan: Scientific Counselor Embassy of Japan, Washington, D.C., unpublished statistics.
United Kingdom: Cabinet Office, The Central Statistical Office, London, unpublished statistics.
West Germany: Bundesministerium für Forschung und Technologie, unpublished statistics.
United States: National Science Foundation, unpublished data.
U.S.S.R.: Dr. Robert W. Campbell, *Reference Source on USSR R & D Statistics, 1950–1978,* National Science Foundation 1978; Steven Rapawy, *Estimates and Projections of the Labor Force and Civilian Employment in the U.S.S.R., 1950 to 1990,* Foreign Economic Report No. 10, U.S. Department of Commerce, 1976, p. 19; Robert W. Campbell, *Soviet R & D Statistics 1975–1982,* National Science Foundation, 1983.

See figure 1-2.

Appendix table 1-4. First degrees conferred by higher educational institutions, by major field of study for selected countries: 1960–80

Field of study	1960		1965		1970		1975		1976		1977		1979		1980		
	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	Japan
	Number (in thousands)																
All fields total	394.9	343.3	538.9	403.9	833.3	630.8	987.9	713.4	997.5	734.6	993.0	751.9	1000.6	790.0	1010.8	817.3	378.7
Natural science and engineering total	89.4	162.5	109.3	211.8	147.6	328.5	161.4	370.9	164.4	383.4	168.7	397.9	179.6	416.9	185.7	436.5	98.9
Physical and life sciences and mathematics[1]	45.3	25.1	65.7	25.6	91.4	39.7	96.5	44.9	98.2	46.3	97.5	47.8	93.6	49.8	93.5	52.2	11.6
Engineering[3]	37.8	102.9	36.8	152.3	44.8	230.5	47.3	272.1	46.7	280.4	49.7	291.4	62.8	306.8	69.3	319.8	73.5
Agriculture	6.3	34.5	6.8	33.9	11.4	58.3	17.6	53.9	19.5	56.7	21.5	58.7	23.2	60.3	22.9	64.5	13.9
Other fields[4]	305.5	180.8	429.6	192.1	685.7	302.3	826.5	342.5	833.1	351.2	824.3	354.0	821.0	373.1	825.1	380.8	279.8
	As a percent of the 22/23 year old population[2]																
All fields total	17.6	7.8	18.1	13.3	23.9	19.3	26.0	16.4	25.6	17.1	23.5	16.8	24.1	16.4	23.6	16.8	24.3
Natural science and engineering total	4.0	3.7	3.7	7.0	4.2	10.1	4.3	8.5	4.2	8.9	4.3	8.9	4.3	8.7	4.3	9.0	6.3
Physical and life sciences and mathematics[1]	2.0	.6	2.2	.8	2.6	1.2	2.5	1.0	2.5	1.1	2.5	1.1	2.3	1.0	2.2	1.1	.7
Engineering[3]	1.7	2.3	1.2	5.0	1.3	7.1	1.2	6.2	1.2	6.5	1.3	6.5	1.5	6.4	1.6	6.6	4.7
Agriculture	.3	.8	.2	1.1	.3	1.8	.5	1.2	.5	1.3	.5	1.3	.6	1.3	.5	1.3	.9
Other fields[4]	13.6	4.1	14.4	6.3	19.6	9.3	21.8	7.9	21.4	8.2	20.8	7.9	19.8	7.8	19.3	7.8	17.9

[1]Figures for the U.S.S.R. are estimates made to approximate the U.S. definitions.

[2]Based on 22-year-olds for the U.S. and on 23-year-olds for the U.S.S.R., because of the differences in average length of years required to receive a first degree. Figures for Japan are an average of 20–24 year olds.

[3]Includes first professional degrees and technology engineers for the United States. Under NSF definitions which exclude engineering technology, the number of U.S. engineering degrees in 1980 was 59,240, or 6 percent of the total.

[4]Includes social sciences and health fields.

SOURCES: Catherine P. Ailes and Francis W. Rushing, *The Science Race: Training and Utilization of Scientists and Engineers, U.S. and U.S.S.R.* (New York: Crane Russak, 1982) p. 68. Updated U.S. and U.S.S.R. data for 1980 provided by Catherine P. Ailes, Japanese data from *Statistical Abstract of Education Science and Culture,* Ministry of Education Science and Culture (Tokyo, Japan, 1981), p. 96 and *1980 Population Census of Japan,* Statistics Bureau, Prime Minister's Office, (Tokyo, Japan, 1981), p. 10.

See figure 1-3.

Appendix table 1-5. National expenditures for performance of R&D as a percent of gross national product (GNP) by country: 1961-83

Year	France	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Ratio of R&D expenditures to gross national product[1]					
1961	1.38	NA	1.39	2.45	2.73	NA
1962	1.46	1.25	1.47	NA	2.72	2.64
1963	1.55	1.41	1.44	NA	2.86	2.80
1964	1.81	1.57	1.48	2.29	2.96	2.87
1965	2.01	1.73	1.52	NA	2.90	2.85
1966	2.06	1.81	1.46	2.31	2.89	2.88
1967	2.13	1.97	1.52	2.29	2.89	2.91
1968	2.08	1.97	1.60	2.25	2.82	NA
1969	1.94	2.05	1.64	2.22	2.72	3.03
1970	1.91	2.18	1.81	NA	2.63	3.23
1971	1.90	2.38	1.85	NA	2.48	3.29
1972	1.86	2.33	1.86	2.05	2.40	3.58
1973	1.76	2.22	1.90	NA	2.32	3.66
1974	1.79	2.26	1.97	NA	2.29	3.64
1975	1.80	2.38	1.96	2.05	2.27	3.69
1976	1.77	2.29	1.95	NA	2.27	3.55
1977	1.76	2.31	1.93	NA	2.23	3.46
1978	1.76	2.31	1.96	2.13	2.23	3.47
1979	1.81	2.59	2.06	NA	2.27	3.44
1980 (prel.)	1.85	2.65	2.18	NA	2.38	3.67
1981 (prel.)	1.97	2.68	2.36	NA	2.45	3.66
1982 (est.)	NA	NA	NA	NA	2.58	3.65
1983 (est.)	NA	NA	NA	NA	2.65	NA
	R&D expenditures (national currency in billions)[2]					
1961	4.5	NA	275.5	0.68	14.3	NA
1962	5.4	4.5	319.3	NA	15.4	5.2
1963	6.4	5.4	368.3	NA	17.1	5.8
1964	8.3	6.6	438.1	.77	18.9	6.4
1965	9.8	7.9	508.6	NA	20.0	6.9
1966	11.0	8.8	576.6	.89	21.8	7.5
1967	12.2	9.7	702.5	.93	23.1	8.2
1968	13.1	10.6	877.5	.99	24.6	9.0
1969	14.2	12.2	1,064.7	1.05	25.6	10.0
1970	15.0	14.8	1,355.5	NA	26.1	11.7
1971	16.6	18.0	1,532.4	NA	26.7	13.0
1972	18.3	19.2	1,791.9	1.31	28.5	14.4
1973	19.8	20.5	2,215.8	NA	30.7	15.7
1974	23.0	22.3	2,716.0	NA	32.9	16.5
1975	26.2	24.6	2,974.6	2.15	35.2	17.4
1976	29.8	25.7	3,320.7	NA	39.0	17.7
1977	33.2	27.7	3,651.3	NA	42.8	18.3
1978	37.7	29.9	4,045.9	3.51	48.2	19.3
1979	44.1	36.1	4,583.6	NA	55.0	20.2
1980 (prel.)	51.0	39.3	5,246.2	NA	62.7	22.3
1981 (est.)	61.0	41.3	5,982.4	NA	72.1	23.4
1982 (est.)	NA	NA	NA	NA	79.0	24.0
1983 (est.)	NA	NA	NA	NA	86.5	25.5

(continued)

Table 1-5 (Continued)

Year	France[3]	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Gross national product (national currency in billions)					
1961	328.4	331.4	19,852.8	27.5	524.6	NA
1962	367.2	360.5	21,659.5	28.9	565.0	197.2
1963	412.0	382.1	25,592.1	30.8	596.7	206.8
1964	456.7	419.6	29.661.9	33.5	637.7	223.2
1965	489.8	458.2	33,550.2	36.0	691.1	242.1
1966	532.0	487.4	39,452.0	38.4	756.0	260.1
1967	574.8	493.7	46,175.6	40.5	799.6	282.0
1968	630.0	535.2	54,689.2	43.8	873.4	NA
1969	734.0	597.7	64,850.8	47.1	944.0	329.6
1970	782.0	679.0	75,091.6	51.6	992.7	362.2
1971	873.1	756.0	82,725.8	57.8	1,077.6	394.8
1972	961.3	827.2	96,424.0	63.9	1,185.9	401.8
1973	1,121.3	920.1	116,636.3	74.2	1,326.4	429.4
1974	1,284.4	986.9	138,044.6	84.3	1,434.2	453.1
1975	1,452.0	1,034.9	151,797.0	105.2	1,549.2	471.8
1976	1,677.8	1,125.0	170,290.0	125.7	1,718.0	498.6
1977	1,885.0	1,200.0	188,804.3	143.2	1,918.3	528.8
1978	2,141.0	1,290.7	206,762.5	164.6	2,163.9	556.8
1979	2,439.0	1,395.3	222,043.1	191.1	2,417.8	587.9
1980 (prel.)	2,759.0	1,484.2	240,647.0	223.0	2,633.1	607.7
1981 (est.)	3,094.0	1,543.1	253,811.2	NA	2,937.7	640.1
1982 (est.)	NA	NA	NA	NA	3,057.6	658.1
1983 (est.)	NA	NA	NA	NA	3,262.0	NA

[1] Calculated from unrounded figures.

[2] Gross expenditures for performance of R&D including associated capital expenditures except for the United States where total capital expenditure data are not available. U.S. estimates for the period 1972-80 show that the inclusion of capital expenditures would have an impact of less than one tenth of one percent on the R&D/GNP ratio.

[3] Gross domestic product.

NA = not available.

NOTE: The latest for each country data may be preliminary or estimates. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

SOURCES: International Monetary Fund, *International Financial Statistics*, vol. 30 (May 1977); vol. 31 (May 1978); vol. 31 (August 1978); vol. 32 (January 1979); and vol. 33 (August 1980); and U.S. Department of Commerce, *International Economic Indicators* (June 1982)

France: Délégation Générale à la Recherche Scientifique et Technique, unpublished statistics.

Japan: Scientific Counselor Embassy of Japan, Washington, D.C., unpublished statistics.

United Kingdom: Cabinet Office, The Central Statistical Office, London, unpublished statistics.

West Germany: Bundesministerium für Forschung und Technologie, unpublished statistics.

United States: National Science Foundation, *National Patterns of Science and Technology Resources 1983*, in press.

U.S.S.R.: Robert W. Campbell, *Reference Source on Soviet R&D Statistics, 1950-1978*, National Science Foundation 1978, and Robert W. Campbell, *Soviet R&D Statistics 1975-1982*, National Science Foundation, 1983.

See figure 1-4.

Science Indicators—1982

Appendix table 1-6. Estimated ratio of civilian R&D expenditures[1] to gross national product (GNP) for selected countries: 1961-83

Year	France	West Germany	Japan	United Kingdom	United States
	Estimated civilian R&D expenditures as a percent of GNP				
1961	0.97	NA	1.37	1.48	1.20
1962	1.03	1.14	1.46	NA	1.23
1963	1.10	1.26	1.43	NA	1.29
1964	1.34	1.38	1.47	1.49	1.27
1965	1.37	1.53	1.50	NA	1.33
1966	1.40	1.62	1.44	1.58	1.39
1967	1.50	1.70	1.49	1.65	1.48
1968	1.54	1.72	1.57	1.66	1.47
1969	1.52	1.81	1.61	1.66	1.49
1970	1.47	1.96	1.77	NA	1.50
1971	1.33	2.16	1.82	NA	1.46
1972	1.35	2.13	1.82	1.48	1.42
1973	1.30	2.02	1.86	NA	1.44
1974	1.36	2.07	1.91	NA	1.49
1975	1.39	2.19	1.90	1.38	1.50
1976	1.36	2.10	1.89	NA	1.50
1977	1.38	2.13	1.87	NA	1.50
1978	1.36	2.13	1.90	1.49	1.54
1979	1.38	2.41	2.01	NA	1.59
1980 (prel.)	1.39	2.48	2.13	NA	1.69
1981 (est.)	NA	2.53	2.30	NA	1.69
1982 (est.)	NA	NA	NA	NA	1.76
1983 (est.)	NA	NA	NA	NA	1.75
	Estimated civilian R&D expenditures[2] (national currency in billions)				
1961	3.2	NA	272.8	0.41	6.30
1962	3.8	4.1	316.5	NA	6.93
1963	4.6	4.8	365.2	NA	7.68
1964	6.1	5.8	434.7	.50	8.41
1965	6.7	7.0	504.5	NA	9.22
1966	7.4	7.9	571.6	.61	10.49
1967	8.6	8.4	695.8	.70	11.80
1968	9.7	9.2	868.9	.73	12.80
1969	11.0	10.8	1,055.4	.78	14.10
1970	11.5	13.3	1,333.3	NA	14.90
1971	12.0	16.3	1,508.0	NA	15.74
1972	13.6	17.6	1,758.0	.95	16.80
1973	14.6	18.6	2,173.2	NA	19.05
1974	17.5	20.4	2,655.4	NA	21.36
1975	20.2	22.7	2,892.5	1.45	23.24
1976	23.2	23.6	3,225.5	NA	25.75
1977	26.0	25.6	3,565.1	NA	28.70
1978	29.0	27.5	3,925.6	2.46	33.25
1979	33.6	33.6	4,456.5	NA	38.48
1980 (prel.)	38.4	36.8	5,114.6	NA	44.54
1981 (est.)	NA	39.0	5,844.8	NA	49.76
1982 (est.)	NA	NA	NA	NA	53.72
1983 (est.)	NA	NA	NA	NA	57.09

(continued)

Table 1-6. (Continued)

Year	France[3]	West Germany	Japan	United Kingdom	United States
	Gross national product (national currency in billions)				
1961	328.4	331.4	19,852.8	27.5	524.6
1962	367.2	360.5	21,659.5	28.9	565.0
1963	412.0	382.1	25,592.1	30.8	596.7
1964	456.7	419.6	29,661.9	33.5	637.7
1965	489.8	458.2	33,550.2	36.0	691.1
1966	532.0	487.4	39,452.0	38.4	756.0
1967	574.8	493.7	46,175.6	40.5	799.6
1968	630.0	535.2	54,689.2	43.8	873.4
1969	734.0	597.7	64,850.8	47.1	944.0
1970	782.0	679.0	75,091.6	51.6	992.7
1971	873.1	756.0	82,725.8	57.8	1,077.6
1972	961.3	827.2	96,424.0	63.9	1,185.9
1973	1,121.3	920.1	116,636.3	74.2	1,326.4
1974	1,284.4	986.9	138,044.6	84.3	1,434,2
1975	1,452.0	1,034.9	151,797.0	105.2	1,549.2
1976	1,677.8	1,125.0	170,290.0	125.7	1,718.0
1977	1,885.0	1,200.5	188,804.3	143.2	1,918,3
1978	2,141.0	1,290.7	206,762.5	164.6	2,163.9
1979	2,439.0	1,395.3	222,043.1	191.1	2,417.8
1980 (prel.)	2,759.0	1,484.2	240,647.0	223.0	2,633.1
1981 (est.)	3,094.0	1,543.1	253,811.2	NA	2,937.7
1982 (est.)	NA	NA	NA	NA	3,057.6
1983 (est.)	NA	NA	NA	NA	3,262.0

[1] National expenditures for R&D, excluding Government funds for defense and space.

[2] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States, where total capital expenditure data are not available.

[3] Gross domestic product.

NA = Not available.

NOTE: The latest data from these sources may be preliminary or estimates. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

SOURCES: Calculated from appendix table 1-3 and data from country sources listed there and Organisation for Economic Co-operation and Development, *Changing Priorities for Government R&D* (Paris, 1975), OECD *International Survey of the Resources Devoted to R&D by Member Countries, International Statistical Year—1973: The Objectives of Government R&D Funding 1970-76* vol. 2B (Paris, 1977), *Science and Technology Indicators, vol. A, The Objectives of Government R&D Funding, 1969-1981* (Paris, 1981), and National Science Foundation, unpublished statistics.

See figure 1-5.

Science Indicators—1982

Appendix table 1-7. Distribution of Government support of R&D by national objective[1], by country: 1970-80

(Percent)

Objective	United States			Japan[2]		West Germany			France		United Kingdom		
	1971	1975	1980	1975	1980	1970	1975	1980	1975	1980	1970	1975	1980
Defense and aerospace	75.3	67.5	63.7	19.5	16.8	41.8	29.4	24.4	45.6	49.3	NA	63.2	64.8
Defense	52.2	50.8	47.3	4.7	4.9	29.5	19.2	15.3	32.8	40.1	72.3	52.8	59.4
Space	19.6	14.5	14.5	14.8	12.0	8.8	7.4	6.6	6.1	6.8	3.3	2.5	2.3
Civil aeronautics	3.6	2.1	1.9	—	—	3.5	2.9	2.4	6.8	2.4	NA	7.9	3.1
Agriculture and industry	2.5	2.5	3.0	41.9	37.6	10.9	13.2	15.3	13.1	12.2	NA	8.2	8.3
Agriculture	2.0	2.2	2.7	27.7	25.4	3.5	3.3	2.9	4.2	4.3	4.2	4.8	4.5
Industrial growth	.6	.3	.3	14.2	12.2	7.4	9.9	12.4	8.9	7.9	NA	3.4	3.8
Energy and infrastructure	6.6	10.9	14.2	22.9	34.4	23.4	25.9	30.9	17.6	16.0	16.0	10.3	10.1
Production of energy	3.6	7.2	11.4	16.0	26.2	18.8	18.3	20.9	9.4	8.3	12.3	7.1	7.3
Transport, telecommunications	1.1	1.2	.9	3.9	2.9	—	2.5	3.2	3.3	3.0	1.4	.7	.7
Urban and rural planning	.4	.5	.4	1.2	2.3	.8	1.9	5.7	1.6	1.5	1.9	1.8	1.1
Earth and atmosphere	1.5	2.0	1.6	1.8	2.9	2.8	3.1	4.3	3.3	3.3	.5	.8	1.0
Health and welfare	12.2	14.8	15.2	12.1	11.2	8.6	15.9	15.3	6.5	7.5	4.1	4.1	3.9
Environmental protection	.9	.9	.8	3.2	3.4	.6	1.7	3.1	.9	1.2	.7	.6	.9
Health	8.7	11.9	12.1	6.3	6.1	3.5	5.6	9.3	4.4	4.9	2.3	2.3	1.8
Social development and services	2.6	2.1	2.3	2.5	1.7	4.5	8.5	6.0	1.2	1.4	1.1	1.2	1.2
Advancement of knowledge	3.3	4.3	3.0	3.5	4.1	15.3	15.7	14.2	17.1	15.0	NA	14.1	12.9
Total specified R&D funding	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Excluding general university funds (G.U.F.)
[2] Government intramural expenditure only.

SOURCE: Organisation for Economic Co-operation and Development, *OECD Science and Technology Indicators I*, (Paris, 1982), p. 83.

See figure 1-6.

Science Indicators—1982

Appendix table 1-8. R&D performed in the business enterprise sector by source of funds: 1970, 1975 and 1979

	National currency (in millions)			Percent		
Country and source	1970	1975	1979	1970	1975	1979
France	8,322.4	15,616.5	26,260.0	100.0	100.0	100.0
Total domestic	8,007.3	14,393.5	24,460.0	96.2	92.2	93.1
Business enterprise	5,310.0	9,965.8	18,723.0	63.8	63.8	71.3
Government	2,689.0	4,376.8	5,674.0	32.3	28.0	21.6
Private nonprofit	4.6	47.2	58.0	.1	.3	.2
Higher education	3.7	3.7	5.0	—	—	—
From abroad	315.1	1,223.0	1,800.0	3.8	7.8	6.9
Japan	895,020.0	1,684,847.0	2,664,913.0	100.0	100.0	100.0
Total domestic	894,193.0	1,683,200.0	2,662,698.0	99.9	99.9	99.9
Business enterprise	876,608.0	1,654,502.0	2,624,843.0	97.9	98.2	98.5
Government	17,585.0	28,698.0	36,807.0	2.0	1.7	1.4
Private nonprofit	NA	NA	935.0	NA	NA	—
Higher education	NA	NA	113.0	NA	NA	—
From abroad	827.0	1,647.0	2,215.0	.1	.1	.1
United Kingdom[1]	680.3	1,340.2	2,324.3	100.0	100.0	100.0
Total domestic	647.7	1,255.5	2,138.8	95.2	93.7	92.0
Business enterprise	431.2	841.4	1,459.0	63.4	62.8	62.8
Government	216.5	414.1	679.7	31.8	30.9	29.2
Private nonprofit	NA	NA	NA	NA	NA	NA
Higher education	NA	NA	NA	NA	NA	NA
From abroad	32.6	84.7	185.5	4.8	6.3	8.0
United States[2]	18,067.0	24,187.0	38,226.0	100.0	100.0	100.0
Total domestic	18,067.0	24,187.0	38,226.0	100.0	100.0	100.0
Business enterprise	10,288.0	15,582.0	25,708.0	56.9	64.4	67.3
Government	7,779.0	8,605.0	12,518.0	43.1	35.6	32.7
Private nonprofit	—	—	—	—	—	—
Higher education	—	—	—	—	—	—
From abroad	—	—	—	—	—	—
West Germany[3]	7,114.0	14,469.0	20,720.0	100.0	100.0	100.0
Total domestic	7,090.0	14,005.0	20,070.0	—	96.8	96.9
Business enterprise	6,146.0	11,397.0	15,650.0	—	78.8	75.5
Government	939.0	2,596.0	4,400.0	—	17.9	21.2
Private nonprofit	5.0	12.0	20.0	—	.1	.1
Higher education	—	—	—	—	—	—
From abroad	24.0	464.0	650.0	—	3.2	3.1

[1] 1970 figures for the United Kingdom are from 1969, and 1979 figures are from 1978.

[2] Current expenditures plus depreciation only.

[3] 1970 figures for West Germany are from 1969.

NA = Not separately available.

NOTE: Details may not add to totals because of rounding.

SOURCES: Organisation of Economic Co-operation and Development, *OECD Science and Technology Indicators, vol. B* (Paris, 1982) and National Science Foundation, *Research and Development in Industry 1981*, in press.

Science Indicators—1982

Appendix table 1-9. Industrial R&D expenditures as a percentage of the domestic product of industry: 1967-79

Country and year	National currency in millions		BERD/DPI (in percent)
	BERD[1]	DPI[2]	
United States			
1967	16,385	659,200	2.49
1971	18,320	878,300	2.09
1975	24,187	1,253,000	1.93
1979	38,226	1,973,000	1.94
United Kingdom			
1967	605	30,212	2.00
1971	831	48,037	1.73
1975	1,340	78,075	1.72
1978	2,324	124,354	1.87
West Germany			
1967	5,683	444,070	1.28
1971	10,521	657,390	1.60
1975	14,469	875,330	1.65
1979	23,120	1,184,810	1.95
France			
1967	6,292	442,700	1.42
1971	9,336	695,297	1.34
1975	15,617	1,150,085	1.36
1979	26,260	1,918,245	1.37
Japan			
1967	378,969	45,315,500	.84
1971	895,020	73,641,000	1.22
1975	1,684,847	131,474,000	1.28
1979	2,664,913	193,857,000	1.38

[1] Business enterprise R&D (total industrial R&D expenditures).
[2] The domestic product of industry.

NOTE: The industrial R&D expenditures (BERD) and the domestic industrial product (DPI) figures are shown in millions of national currency.

SOURCES: Organisation of Economic Co-operation and Development, *International Survey of the Resources Devoted to R&D by Member Countries, International Statistical Year, 1971,* (Paris, 1974) and unpublished tabulations from OECD, 1982.

Science Indicators—1982

Appendix table 1-10. Percent of private industrial R&D in selected industries: 1969-79

Industry	United States		Japan		West Germany		United Kingdom		France	
	1970	1979	1970	1979	1969	1979	1969	1978	1971	1979
Six-industry total	71.2	70.2	61.5	55.6	71.1	72.4	58.4	60.7	NA	61.7
Aerospace	11.8	8.6	—	—	.1	.6	1.1	5.4	7.8	8.8
Electrical and electronics	19.5	17.6	24.9	23.4	29.3	26.9	20.4	16.0	16.5	20.2
Instruments	5.3	7.8	2.3	2.9	1.6	2.1	3.1	1.9	NA	1.2
Machinery	14.3	6.0	8.7	7.0	7.0	16.6	8.8	6.6	NA	4.2
Computers		11.5	2.9	2.8			2.9	5.2	NA	3.9
Chemicals group[1]	20.3	18.7	22.7	19.5	33.1	26.2	22.1	25.6	24.2	23.4

[1] Includes chemicals and allied products and petroleum refining industries.

SOURCES: Organisation for Economic Co-operation and Development, *OECD Science and Technology Indicators I*, vol. D, (Paris, 1982), and National Science Foundation, *Research and Development in Industry 1981*, in press.

Science Indicators—1982

Appendix table 1-11. Percent of total industrial R&D concentration in selected industries: 1969-79

Industry	United States		Japan		West Germany		United Kingdom		France	
	1970	1979	1970	1979	1969	1979	1969	1978	1970	1979
Six-industry total	78.7	74.6	61.1	55.3	73.0	69.8	71.9	72.8	72.1	69.1
Aerospace	28.9	21.0	—	—	7.0	5.8	23.1	18.3	20.5	18.1
Electrical and electronics	23.4	20.5	24.8	23.3	28.1	25.2	20.7	24.1	21.2	23.3
Instruments	4.1	6.6	2.3	2.9	1.5	1.9	2.5	1.5	1.1	1.2
Machinery	9.6	4.2	8.8	7.0	7.6	14.8	7.1	4.7	5.9	3.4
Computers		8.4	2.8	2.8			3.4	6.2	5.4	4.9
Chemicals and allied products	12.7	13.9	22.4	19.4	28.8	22.1	15.1	18.0	18.0	18.2

SOURCES: Organisation for Economic Co-operation and Development *OECD Science and Technology Indicators I*, vol. D, (Paris, 1982), and National Science Foundation, *Research and Development in Industry 1981*, in press.

Science Indicators—1982

Appendix table 1-12. U.S. and world scientific and technical articles[1] by field: 1973-80

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980
	U.S. articles as a percent of all articles							
All fields	38	38	37	37	37	38	37	37
Clinical medicine	43	43	43	43	43	43	43	43
Biomedicine	39	38	39	39	39	39	40	40
Biology	46	46	45	44	42	42	43	42
Chemistry	23	22	22	22	22	21	21	21
Physics	33	33	32	31	30	31	30	30
Earth and space sciences	47	47	44	46	45	45	45	42
Engineering and technology	42	42	41	41	40	39	41	39
Mathematics	48	46	44	43	41	40	40	40
	Number of U.S. articles[3]							
All fields	103,777	100,066	97,278	99,970	97,854	99,207	99,377	98,394
Clinical medicine	32,638	31,691	31,334	32,920	33,516	34,966	33,975	34,612
Biomedicine	16,115	15,607	15,901	16,271	16,197	16,611	17,649	17,582
Biology	11,150	10,700	10,400	10,573	9,904	9,663	10,553	9,594
Chemistry	10,474	9,867	9,222	9,337	8,852	9,266	9,182	9,250
Physics	11,721	11,945	11,363	11,502	10,995	11,015	10,995	11,415
Earth and space sciences	5,591	5,371	4,975	5,537	5,197	5,043	5,167	4,832
Engineering and technology	11,955	11,088	10,431	10,346	10,081	9,694	9,018	8,461
Mathematics	4,134	3,797	3,652	3,484	3,112	2,949	2,838	2,648
	Number of all articles							
All fields	271,513	265,130	260,908	267,354	263,700	270,128	267,953	269,556
Clinical medicine	76,209	74,509	73,485	76,699	77,597	81,209	78,827	80,533
Biomedicine	41,155	40,632	41,244	41,891	41,388	42,968	43,631	44,267
Biology	24,047	23,414	23,260	23,905	23,757	23,176	24,734	22,838
Chemistry	45,004	44,529	42,502	42,773	40,734	43,550	43,273	44,448
Physics	35,854	35,708	35,104	36,902	36,057	35,515	36,700	37,944
Earth and space sciences	11,977	11,479	11,356	12,011	11,531	11,224	11,596	11,395
Engineering and technology	28,617	26,600	25,664	25,146	25,003	24,588	22,182	21,459
Mathematics	8,639	8,259	8,293	8,127	7,573	7,298	7,011	6,673

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-13 for the subfields included in these fields.

[3] When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States, it is split on the basis of these countries regardless of the number of organizations represented by the authors.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-2 in text.

Science Indicators—1982

Appendix table 1-13. Fields and subfields of international scientific literature: 1980

Field and subfield	Number of articles: World	Number of articles: United States	Field and subfield	Number of articles: World	Number of articles: United States
Clinical medicine	80,533	34,612	Marine biology & hydrobiology	1,532	567
General & internal medicine	14,575	4,948	Botany	6,192	2,572
Allergy	543	227	Ecology	1,327	786
Anesthesiology	1,009	393	Agriculture & food science	6,291	2,770
Cancer	3,496	1,755	Dairy animal science	425	128
Cardiovascular system	3,070	1,453	Miscellaneous biology	1,479	295
Dentistry	1,758	1,051			
Dermatology & venereal diseases	1,203	389	Chemistry	44,448	9,250
Endocrinology	3,173	1,389	Analytical chemistry	4,138	1,233
Fertility	921	475	Organic chemistry	7,209	1,859
Gastroenterology	1,291	420	Inorganic & nuclear chemistry	2,883	704
Geriatrics	502	297	Applied chemistry	2,479	334
Hematology	1,347	519	General chemistry	14,747	2,141
Immunology	5,269	2,599	Polymers	3,673	856
Obstetrics & gynecology	1,531	783	Physical chemistry	9,319	2,122
Neurology & neurosurgery	5,748	2,605			
Ophthalmology	1,825	766	Physics	37,944	11,415
Orthopedics	818	253	Chemical physics	4,598	1,905
Arthritis & rheumatism	427	153	Solid state physics	6,068	1,449
Otorhinoloaryngology	869	504	Fluids & plasmas	851	450
Pathology	2,163	840	Applied physics	9,192	2,674
Pediatrics	2,723	1,290	Acoustics	1,108	508
Pharmacology	7,293	2,670	Optics	1,472	718
Pharmacy	3,164	911	General physics	11,378	2,227
Psychiatry	1,662	1,016	Nuclear & particle physics	2,586	1,162
Radiology & nuclear medicine	3,178	1,448	Miscellaneous physics	691	292
Respiratory system	734	302			
Surgery	4,197	2,153	Earth and space science	11,395	4,832
Tropical medicine	587	117	Astronomy & astrophysics	3,527	1,554
Urology	865	496	Meteorology & atmospheric science	801	459
Nephrology	247	138	Geology	1,737	811
Veterinary medicine	2,552	1,124	Earth & planetary science	4,447	1,746
Addictive diseases	250	162	Geography	34	8
Hygiene & public health	1,230	752	Oceanography & limnology	849	254
Miscellaneous clinical medicine	310	215			
			Engineering and technology	21,459	8,461
Biomedicine	44,267	17,582	Chemical engineering	2,383	1,138
Physiology	2,824	1,206	Mechanical engineering	1,998	825
Anatomy & morphology	624	208	Civil engineering	1,140	677
Embryology	639	355	Electrical engineering & electronics	5,735	2,277
Genetics & heredity	3,331	1,125	Miscellaneous engineering & technology	31	21
Nutrition & dietetics	1,480	728	General engineering	1,252	251
Biochemistry & molecular biology	15,090	6,205	Metals & metallurgy	2,746	508
Biophysics	830	313	Materials science	2,257	833
Cell biology, cytology & histology	3,286	1,286	Nuclear technology	1,691	749
Microbiology	3,278	1,064	Aerospace technology	630	366
Virology	1,525	729	Computers	968	505
Parasitology	768	357	Library & information science	155	117
Biomedical engineering	929	366	Operations research & management science	472	193
Microscopy	241	73			
Miscellaneous biomedicine	1,040	608			
General biomedicine	8,382	2,960			
			Mathematics	6,673	2,648
Biology	22,838	9,594	Probability and statistics	1,043	564
General biology	1,452	492	Applied mathematics	987	354
General zoology	959	277	General mathematics	4,293	1,539
Entomology	1,425	766	Miscellaneous mathematics	350	191
Miscellaneous zoology	1,756	833	All fields	269,556	98,394

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 1-14. Relative citation ratios[1] for U.S. articles[2] by field: 1973-78

Source of citations	Cited year	All fields	Clinical medicine	Biomedicine	Biology	Chemistry	Physics	Earth and space sciences	Engineering and technology	Mathematics
World citations to U.S.	1973	1.40	1.35	1.42	1.07	1.66	1.53	1.39	1.28	1.23
	1974	1.41	1.36	1.43	1.10	1.67	1.53	1.40	1.27	1.22
	1975	1.42	1.36	1.41	1.10	1.71	1.55	1.46	1.25	1.22
	1976	1.41	1.35	1.40	1.09	1.70	1.59	1.39	1.22	1.21
	1977	1.44	1.37	1.40	1.13	1.80	1.59	1.45	1.29	1.28
	1978	1.45	1.39	1.36	1.09	1.88	1.57	1.46	1.33	1.37
U.S. citations to U.S.	1973	1.87	1.72	1.81	1.58	2.71	2.12	1.66	1.80	1.61
	1974	1.92	1.74	1.85	1.65	2.85	2.14	1.67	1.84	1.64
	1975	1.94	1.74	1.84	1.67	2.91	2.22	1.77	1.87	1.70
	1976	1.95	1.75	1.85	1.69	2.95	2.30	1.67	1.83	1.75
	1977	1.97	1.75	1.82	1.76	3.04	2.31	1.73	1.87	1.78
	1978	1.99	1.77	1.80	1.75	3.16	2.31	1.71	1.95	1.86
Non-U.S. citations to U.S.	1973	1.01	.99	1.07	.67	1.17	1.15	1.06	.86	.85
	1974	.98	.98	1.03	.65	1.12	1.11	1.05	.79	.82
	1975	.97	.97	1.01	.63	1.13	1.10	1.09	.74	.78
	1976	.94	.94	.98	.59	1.08	1.10	1.01	.69	.74
	1977	.98	.98	.97	.62	1.19	1.09	1.09	.76	.82
	1978	.96	.98	.90	.57	1.25	1.04	1.11	.79	.90

[1] A citation ratio of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U.S. articles for that year. For example, the U.S. biology literature for 1973 received 7 percent more citations from the world literature of later years than could be accounted for by the U.S. share of the world's biology articles published in 1973.

[2] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[3] See appendix table 1-13 for a description of the subfields included in these fields.

NOTE: These ratios are calculated by a method that used citations from articles from the 1973-80 *Science Citation Index* to describe the utilization of a given year's literature.

SOURCE: Computer Horizons, Inc., unpublished data

See table 1-3 in text.

Appendix table 1-15. U.S. patents granted to inventors from selected countries, by date of grant and nationality of inventor: 1966–82

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Total	68,405	65,652	59,103	67,559	64,429	78,317	74,810	74,143	76,278	72,002	70,226	65,269	66,102	48,854	61,819	65,771	57,889
United States	54,634	51,274	45,783	50,395	47,077	55,958	51,524	51,504	50,649	46,713	44,277	41,484	41,254	30,081	37,356	39,223	33,896
Foreign	13,771	14,378	13,320	17,164	17,352	22,333	23,268	22,639	25,629	25,289	25,949	23,785	24,848	18,773	24,463	26,548	23,993
West Germany	3,981	3,766	3,442	4,523	4,435	5,522	5,729	5,587	6,153	6,036	6,180	5,537	5,850	4,527	5,747	6,252	5,409
Japan	1,122	1,424	1,464	2,152	2,625	4,029	5,151	4,939	5,888	6,352	6,543	6,217	6,911	5,251	7,124	8,388	8,149
United Kingdom	2,674	2,800	2,481	3,178	2,954	3,464	3,167	2,855	3,145	3,043	2,990	2,651	2,722	1,910	2,406	2,475	2,134
France	1,435	1,558	1,446	1,809	1,731	2,214	2,229	2,143	2,566	2,367	2,408	2,108	2,119	1,604	2,088	2,181	1,975
Switzerland	983	948	822	1,058	1,112	1,281	1,305	1,326	1,454	1,456	1,475	1,347	1,330	1,025	1,265	1,239	1,147
Canada	938	991	897	993	1,066	1,326	1,241	1,346	1,326	1,296	1,192	1,219	1,226	862	1,080	1,135	990
U.S.S.R.	66	115	95	159	218	333	356	382	492	421	426	394	412	354	460	373	209
Other E.E.C. countries[1]	782	821	744	938	927	1,203	1,191	1,157	1,291	1,071	1,291	1,151	1,128	846	1,085	1,078	1,014

[1]Other European Economic Community (E.E.C.) countries included here are Belgium, Denmark, Ireland, Luxembourg, and the Netherlands.

NOTE: U.S. patent counts for 1979 are unreliable because the Patent and Trademark Office did not have enough money in that year to print all approved patents.

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of Patent Output of U.S. Industry (1963–1981)*, June 1982, and unpublished data.

See figure 1-7.

Appendix table 1-16. Number of U.S. patents granted to selected foreign countries[1] by product field for the period 1963–81

Country of inventor	All fields	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Total	1,234,643	14,105	12,753	201,786	30,945	17,098	64,353	29,825	16,307	157,200	385,768	133,272	143,156	78,246	27,201	149,425
United States	865,124	9,725	8,235	128,369	17,407	14,596	46,698	21,594	10,204	118,688	264,670	96,556	101,914	53,738	16,931	103,333
Foreign	369,519	4,380	4,518	73,417	13,538	2,502	17,655	8,231	6,103	38,512	121,098	36,716	41,242	24,508	10,270	46,092
West Germany	91,359	589*	1,368*	21,060*	3,135*	456*	4,092*	1,742*	1,245*	8,973*	31,624*	8,462*	7,850*	6,762*	2,748*	11,145*
Japan	77,450	1,534*	877*	15,139*	2,277*	339*	3,767*	1,747*	1,399*	6,032*	20,857*	8,416*	13,013*	4,698*	2,637*	13,353*
United Kingdom	51,138	463*	707*	9,238*	1,820*	531*	2,750*	1,416*	772*	5,990*	17,233*	5,317*	5,976*	4,080*	1,845*	5,478*
France	35,244	305*	337*	6,722*	1,607*	252*	1,720*	864*	588*	3,919*	11,100*	3,758*	4,455*	2,913*	1,229*	3,645*
Switzerland	21,622	245	483*	7,011*	1,496*	57	747	265	254	1,924	6,487	1,906*	1,258	871	179	2,527*
Canada	20,241	248*	130	2,307	444	353*	1,067*	456*	419*	3,030*	7,082*	1,839	1,773	1,382*	373*	1,763
Sweden	13,368	128	103	924	307	47	761	407	320	2,194	5,713	1,348	1,007	1,099	298	1,491
Italy	11,958	116	135	3,122	682	48	578	191	150	1,097	4,283	1,068	847	648	243	932
Netherlands	11,103	232	82	2,129	350	182	498	236	98	1,057	3,195	1,473	2,701*	363	131	1,007
U.S.S.R.	5,111	54	25	759	94	62	93	113	188	359	2,228	813	454	153	63	616
Belgium	4,459	37	55	1,074	188	31	245	175	90	410	1,186	264	360	157	28	945
Austria	4,080	35	22	433	91	19	201	88	153	504	1,795	250	273	205	80	449
Australia	3,585	48	40	454	82	17	219	96	80	581	1,365	246	198	212	76	483
Denmark	2,520	81	29	329	115	7	160	80	11	391	947	295	161	62	30	373
Mexico	1,075	28	5	428	339	3	45	20	31	113	259	44	21	50	23	80
Other foreign[2]	15,206	237	120	2,288	511	98	712	335	305	1,938	5,744	1,217	895	853	287	1,805

*Indicates ranking among the top five foreign countries in this particular product field.
[1]Countries were selected on the basis of being in the top 10 of at least one of the Standard Industrial Classifications.
[2]Other foreign includes patents granted to foreign countries not shown separately.

I	Food and kindred products
II	Textile mill products
III	Chemicals, except drugs and medicines
IV	Drugs and medicines
V	Petroleum and gas extraction and petroleum refining
VI	Rubber and miscellaneous plastics products
VII	Stone, clay, glass, and concrete products
VIII	Primary metals
IX	Fabricated metals
X	Nonelectrical machinery
XI	Electrical equipment except communication equipment
XII	Communication equipment and electronic components
XIII	Motor vehicles and other transportation equipment except aircraft
XIV	Aircraft and parts
XV	Professional and scientific instruments

SOURCE: Compiled from information in Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of the Patent Output of U.S. Industry IV (1963–81)*, 1982.

Appendix table 1-17. Share of foreign patenting in the United States for the three most active countries, by selected product fields: 1981

Product field	Total foreign	West Germany	Japan	United Kingdom	Other foreign
			Percent of foreign		
Chemicals, except drugs and medicines	100	28	27	11	34
Drugs and medicines	100	23	22	14	40
Nonelectrical machinery	100	26	27	9	38
Electrical equipment, except communication equipment	100	21	37	8	34
Communications equipment and electronic components	100	18	44	9	29
Motor vehicles and other equipment except aircraft	100	26	34	9	31
Aircraft and parts	100	28	42	10	21
Professional and scientific instruments	100	22	43	8	27
			Number of patents		
Chemicals, except drugs and medicines	5,338	1,520	1,452	566	1,800
Drugs and medicines	1,288	300	288	182	518
Nonelectrical machinery	8,166	2,088	2,240	731	3,107
Electrical equipment, except communications equipment	2,541	535	952	202	852
Communications equipment and electronic components	3,027	534	1,338	279	876
Motor vehicles and other transportation equipment except aircraft	1,652	429	563	151	509
Aircraft and parts	777	216	323	75	163
Professional and scientific instruments	4,100	892	1,760	329	1,119

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of Patent Output of U.S. Industry (1963-1981)*, June 1982.

See figure 1-8.

Appendix table 1-18. Patents granted in selected countries by nationality of inventor: 1966–81

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981[4]
United States																
Total	68,406	65,652	59,102	67,557	64,427	78,316	74,808	74,139	76,275	71,994	70,236	65,269	66,102	48,853	61,827	65,770
Granted to nationals	54,634	51,274	45,782	50,395	47,073	55,988	51,515	51,501	50,643	46,603	44,162	41,383	40,979	30,605	37,152	39,224
Granted to all foreigners	13,772	14,378	13,320	17,162	17,354	22,328	23,293	22,638	25,632	25,391	26,074	23,886	25,123	18,248	24,675	26,546
Foreign patents granted to U.S.[1]	49,098	47,982	48,229	50,852	48,807	49,849	49,628	43,326	39,990	39,300	38,028	39,477	36,649	32,791	31,301	29,520
West Germany																
Total	22,598	19,871	21,169	22,623	12,887	18,149	20,600	23,934	20,539	18,290	20,965	21,749	23,514	22,534	20,188	13,429
Granted to nationals	13,095	11,520	12,143	12,432	6,386	8,295	9,642	11,191	9,793	9,077	10,395	10,815	11,581	10,895	9,826	6,537
Granted to U.S.	3,733	3,406	3,804	4,483	2,882	4,393	4,575	4,949	3,913	3,140	3,333	3,488	3,819	3,713	3,211	2,229
Granted to all foreigners	9,503	8,351	9,026	10,191	6,501	9,854	10,958	12,743	10,746	9,213	10,570	10,934	11,933	11,639	10,362	6,892
U.S. patents as percent of foreigners	39.3	40.8	42.1	44.0	44.3	44.6	41.8	38.8	36.4	34.1	31.5	31.9	32.0	31.9	31.0	32.3
Japan																
Total	26,315	20,773	27,972	27,657	30,878	36,447	41,454	42,328	39,626	46,728	40,317	52,608	45,504	44,104	46,106	50,904
Granted to nationals	17,373	13,877	18,576	18,787	21,403	24,795	29,101	30,937	30,873	36,992	32,465	43,047	37,648	34,863	38,032	42,080
Granted to U.S.	4,683	3,432	4,903	4,657	4,774	5,700	5,948	5,485	4,432	4,918	4,029	4,884	4,014	4,625	3,968	4,371
Granted to all foreigners	8,942	6,896	9,396	8,870	9,475	11,652	12,353	11,391	8,753	9,736	7,852	9,561	7,856	9,241	8,074	8,824
U.S. patents as percent of foreigners	52.4	49.8	52.2	52.5	50.4	48.9	48.2	48.2	50.6	50.5	51.3	51.1	51.1	50.0	49.1	49.5
United Kingdom																
Total	37,272	38,999	43,038	38,790	40,995	41,554	42,794	39,844	37,808	40,689	39,797	36,549	40,823	20,800	23,804	22,924
Granted to nationals	NA	NA	NA	9,807	10,343	10,376	10,116	9,357	8,971	9,120	8,855	7,722	8,464	4,182	5,158	6,076
Granted to U.S.	14,117	13,676	12,588	12,678	12,728	12,682	13,001	11,717	10,976	11,497	11,024	10,420	11,690	5,951	6,726	6,234
Granted to all foreigners	NA	NA	NA	28,983	30,652	31,178	32,678	30,487	28,837	31,569	30,942	28,827	32,359	16,618	18,646	16,848
U.S. patents as percent of foreigners	NA	NA	NA	43.9	41.5	40.7	39.8	38.4	38.1	36.4	35.6	36.1	36.1	35.8	36.1	37.0
France																
Total	43,950	46,995	47,990	32,020	26,297	51,456	46,217	27,939	24,725	14,320	29,754	31,045	30,530	24,618	28,060	21,477
Granted to nationals	14,881	15,246	15,627	10,288	17,758	13,696	10,767	10,817	9,282	4,962	8,420	8,361	8,083	6,846	8,438	6,855
Granted to U.S.	9,807	10,911	10,794	6,943	5,664	11,973	11,206	5,047	4,719	2,801	6,171	6,671	6,810	5,235	5,581	4,164
Granted to all foreigners	29,069	31,749	32,363	21,732	8,539	37,760	35,450	17,122	15,443	9,358	21,334	22,684	22,447	17,772	19,622	14,622
U.S. patents as percent of foreigners	33.7	34.4	33.4	31.9	66.3	31.7	31.6	29.5	30.6	29.9	28.9	29.4	30.3	29.5	28.4	28.5

(continued)

Table 1-18 (Continued)

Switzerland																
Total	22,507	21,850	17,450	16,775	17,575	16,079	14,921	13,680	12,970	13,700	12,300	22,555	704	6,614	5,961	8,289
Granted to nationals	6,174	5,388	4,277	4,260	4,452	4,165	3,942	3,959	3,647	3,794	3,482	6,320	229	1,638	1,475	1,908
Granted to U.S.	3,468	3,632	3,126	3,110	3,090	2,736	2,528	2,140	2,101	2,070	1,847	3,191	66	1,070	981	1,171
Granted to all foreigners	16,333	16,462	13,173	12,515	13,123	11,914	10,979	9,721	9,323	9,906	8,818	16,235	475	4,976	4,486	6,381
U.S. patents as percent of foreigners	21.2	22.1	23.7	24.9	23.5	23.0	23.0	22.0	22.5	20.9	20.9	19.7	13.9	21.5	21.9	18.4
Canada																
Total	24,417	25,836	25,806	28,981	29,193	29,242	28,295	21,246	21,287	20,544	21,750	20,793	21,796	23,546	23,895	22,696
Granted to nationals	1,222	1,263	1,263	1,461	1,395	1,587	1,551	1,218	1,368	1,280	1,301	1,291	1,404	1,408	1,503	1,369
Granted to U.S.	16,614	17,583	17,583	19,147	18,663	17,992	17,289	12,964	12,785	12,220	12,411	11,931	12,458	13,387	13,386	12,523
Granted to all foreigners	23,195	24,573	24,543	27,520	27,798	27,655	26,744	20,028	19,919	19,264	20,449	19,502	20,392	22,138	22,392	21,327
U.S. patents as percent of foreigners	71.6	71.6	71.6	69.6	67.1	65.1	64.6	64.7	64.2	63.4	60.7	61.2	61.1	60.5	59.8	58.7
Other EEC countries[2]																
Total	25,505	24,133	24,627	26,263	26,124	24,322	24,752	25,280	23,341	22,276	21,713	22,609	19,340	16,357	13,416	11,345
Granted to nationals	2,423	2,337	2,089	2,233	2,078	2,023	2,156	2,074	1,869	1,759	1,720	1,801	1,762	1,648	1,543	1,446
Granted to U.S.	6,483	6,253	6,225	6,777	6,670	6,346	6,287	6,071	5,783	5,455	5,384	5,563	4,602	4,045	3,029	2,992
Granted to all foreigners[3]	23,082	21,796	22,538	24,030	24,046	22,299	22,596	23,206	21,472	20,517	19,993	20,808	17,578	14,709	11,873	9,899
U.S. patents as percent of foreigners	28.1	28.7	27.6	28.2	27.7	28.5	27.8	26.2	26.9	26.6	24.8	26.7	26.2	27.5	25.5	30.2

[1]Includes patents granted to U.S. inventors by all the countries shown here (West Germany, Japan, the United Kingdom, Switzerland, Canada, and "other EEC countries"). Patents granted by France are not included due to the wide fluctuations in French patents granted to foreigners.

[2]Other European Economic Community (EEC) countries included here are Belgium, Denmark, Ireland, Luxemburg, and the Netherlands. Comparable data for Italy are not available.

[3]Based on each country as a unit rather than the group of nations as a unit. For instance, patents granted to Denmark by the Netherlands are considered as non-resident or foreign patents here.

[4]The 1981 data do not include international patent applications filed under the PCT. The figures do include patents granted by the European Patent Convention except for France, Belgium and the Netherlands.

NA = not available.

SOURCE: World Intellectual Property Organization, *Industrial Property Statistics* (Geneva, annual issues of 1967–81).

See figure 1-9

Appendix table 1-19. Patenting activity of 10 foreign multinational corporations[1]: 1969-80 period

Foreign multinational corporation	Country of parent	Number of patents
Bayer A.G.	West Germany	7,289
Philips Gloeilampenfabrieken	Netherlands	5,611
Ciba-Geigy A.G.	Switzerland	5,231
Siemens A.G.	West Germany	4,748
Hoechst A.G.	West Germany	4,048
Hitachi Ltd.	Japan	3,591
Matsushita Electric Industrial Co., Ltd.	Japan	2,709
Fuji Photo Film Co. Ltd.	Japan	1,928
Toshiba Corp.	Japan	1,566
Sony Corp.	Japan	1,378

[1] The 5 European and 5 Japanese corporations with the greatest number of patents granted in the United States over the period 1969-80.

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Tenth Report*, 1981, p. 36.

Science Indicators—1982

Appendix table 1-20. Real gross domestic product[1] per employed person for selected countries compared with the United States: 1950-82

(Index, United States = 100)

Year	United States	France	West Germany	Japan	United Kingdom	Canada
1950	100	43.9	39.6	17.5	53.1	84.3
1955	100	47.0	47.7	21.1	51.9	87.6
1960	100	55.7	60.2	26.9	53.7	88.1
1965	100	62.0	64.0	34.9	51.8	87.1
1970	100	73.5	75.0	52.0	56.5	91.9
1971	100	74.9	74.7	52.5	57.5	93.4
1972	100	77.0	76.1	55.6	56.8	93.7
1973	100	78.5	77.4	57.7	58.6	94.0
1974	100	82.6	81.0	58.9	59.4	96.1
1975	100	83.4	81.8	60.4	59.2	95.3
1976	100	85.4	85.3	61.7	60.6	96.8
1977	100	85.7	86.4	63.0	60.1	95.7
1978	100	88.2	88.0	65.0	61.6	95.7
1979	100	91.4	90.9	67.7	62.2	95.3
1980	100	93.2	92.4	70.9	62.3	94.0
1981	100	93.5	92.4	72.5	62.8	94.3
1982	100	95.5	93.8	74.5	65.7	93.5

[1] Output based on international price weights to enable comparable cross-country comparisons.

SOURCE: Department of Labor, Bureau of Statistics, Office of Productivity and Technology, *Comparative Real Gross Domestic Product, Real GDP per Capita, and Real GDP per Employed Person, 1950-82*, April 1983.

See figure 1-10.

Science Indicators—1982

Appendix table 1-21. Productivity[1] growth in manufacturing industries of selected countries: 1960-82

(Index: 1977 = 100)

Year	United States	France	West Germany	Japan	United Kingdom	USSR
1960	60.0	39.8	40.0	22.0	55.6	55.9
1961	61.6	41.6	42.1	24.9	56.1	57.9
1962	64.3	43.5	44.8	26.0	57.5	59.0
1963	68.9	45.9	46.8	28.1	60.6	62.1
1964	72.3	48.4	50.5	31.8	64.9	64.4
1965	74.5	51.2	53.8	33.1	67.0	68.6
1966	75.3	54.8	55.7	36.5	69.5	68.7
1967	75.3	57.8	59.4	41.9	72.7	70.8
1968	78.0	64.4	63.4	47.1	78.0	73.0
1969	79.3	66.7	67.1	54.5	79.9	75.3
1970	79.1	70.1	68.2	61.4	80.5	77.6
1971	83.9	73.8	71.0	65.3	83.7	81.3
1972	88.2	78.2	75.7	72.7	90.2	84.3
1973	93.0	82.4	80.1	80.2	95.8	89.1
1974	90.8	85.3	84.5	82.1	96.5	92.9
1975	93.4	87.9	89.0	85.3	94.6	96.3
1976	97.5	95.1	95.3	93.3	98.4	97.7
1977	100.0	100.0	100.0	100.0	100.0	100.0
1978	100.8	105.7	103.3	107.9	103.3	102.3
1979	101.5	110.7	108.3	117.4	106.8	104.0
1980	101.7	112.6	109.8	125.4	108.1	NA
1981	104.6	114.4	112.8	126.3	114.2	NA
1982	103.6	122.3	114.7	127.6	118.2	NA

[1] Output per hour.

SOURCES: Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, "International Comparisons of Manufacturing Productivity and Labor Cost Trends, Preliminary Measures for 1982," May 1983, mimeograph. Productivity figures for Soviet Union were provided by Francis Rushing of SRI International.

See figure 1-11.

Science Indicators—1982

Appendix table 1-22. Capital investment, as a percent of output for selected countries[1]: 1960-81

Year	United States	Canada	Japan	France	West Germany	United Kingdom
1960-81	13.9	17.4	25.9	16.1	16.7	14.8
1960-69	13.8	17.5	26.3	16.2	17.5	14.4
1970-79	13.9	16.9	25.7	16.1	16.0	15.2
1980-81	14.6	18.9	24.8	15.2	15.7	15.3

[1] Fixed capital investment excluding residential construction at market prices, as a percent of output at factor cost, in current dollar prices.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, unpublished tables, December 1982.

See figure 1-12.

Science Indicators—1982

Appendix table 1-23. Number of robots installed by type and country: 1981

Country	Programmable: Servo-controlled: Continuous path	Programmable: Servo-controlled: Point-to-point	Programmable: Nonservo: General purpose	Programmable: Nonservo: Diecasting and molding machines	Mechanical transfer devices (pick and place)	Total
Total	1,418	10,701	4,293	13,819	101,947	177,386
Japan	NA	6,899	NA	7,347	53,189	67,435
United States	400	2,000	1,700	600	40,000	44,700
West Germany	290	830	200	100	10,000	11,420
France	120	500	NA	NA	38,000	38,620
USSR	NA	NA	NA	NA	NA	3,000
Switzerland	10	40	NA	NA	8,000	8,050
Sweden	250	150	250	50	100	800
Norway	20	50	120	20	50	260
Czechoslovakia	150	50	100	30	200	530
United Kingdom	356	223	54	80	NA	713
Poland	60	115	15	50	120	360
Denmark	11	25	30	—	110	176
Finland	35	16	43	22	51	167
Belgium	22	20	—	—	82	124
Netherlands	48	3	5	—	15	71
Yugoslavia	2	3	5	—	15	25
Australia	NA	NA	62	NA	120	182
Italy	NA	NA	NA	NA	400	753

NA = Not available.

SOURCE: Robot Institute of America, *Worldwide Robotics Survey and Directory* (Dearborn, Michigan, 1982), p. 2.

See figure 1-13.

Appendix table 1-24. U.S. trade balance[1] in R&D-intensive and non-intensive manufactured product groups: 1960-80.

[Dollars in millions]

Year	R&D-intensive[1]			Non-R&D-intensive		
	Balance[2]	Export	Import	Balance[2]	Export	Import
1960	$ 5,891	$ 7,597	$ 1,706	$ −179	$ 4,962	$ 5,141
1961	6,237	8,018	1,781	−12	4,730	4,742
1962	6,720	8,715	1,995	−691	4,940	5,631
1963	6,958	8,975	2,017	−765	5,284	6,049
1964	7,970	10,267	2,297	−678	6,121	6,799
1965	8,148	11,078	2,930	−2,027	6,281	8,308
1966	7,996	12,174	4,178	−3,325	6,913	10,238
1967	8,817	13,407	4,590	−3,729	7,437	11,166
1968	9,775	15,312	5,537	−6,581	8,506	15,087
1969	10,471	16,955	6,484	−6,698	9,830	16,528
1970	11,722	19,274	7,552	−8,285	10,069	18,354
1971	11,727	20,228	8,501	−11,698	10,215	21,913
1972	11,012	22,003	10,991	−15,039	11,737	26,776
1973	15,101	29,088	13,987	−15,370	15,643	31,013
1974	23,873	41,111	17,238	−15,573	22,412	37,985
1975	29,344	46,439	17,095	−9,474	24,511	33,985
1976	28,964	50,830	21,866	−16,499	26,411	42,910
1977	27,107	53,370	26,263	−23,509	26,781	50,290
1978	29,598	63,908	34,310	−35,379	30,627	66,006
1979	39,285	79,126	39,841	−34,835	37,550	72,385
1980	52,404	98,324	45,920	−33,464	45,646	79,110

[1] R&D-intensive manufactured products are those associated with industries with an average of 25 or more scientists and engineers engaged in R&D per 1,000 employees and total R&D funding amounting to 3.5 percent of net sales. See appendix table 1-25.
[2] Exports less imports.

SOURCE: Department of Commerce, *Overseas Business Reports* August 1967, April 1972, April 1977, August 1979, July 1980, and November 1981.

See figure 1-14.

Science Indicators—1982

Appendix table 1-25. R&D-intensive manufacturing ratios for selected industries: 1981

Industry	R&D per net sales (In percent)	R&D S/E's per 1,000 employees
Chemical and allied products	3.8	45
Nonelectrical machinery	5.2	35
Electronic and electrical equipment	6.8	48
Aircraft and missiles	15.3	97
Professional and scientific instruments	8.3	44

SOURCES: National Science Foundation, *Research and Development in Industry, 1981*, in press.

Science Indicators—1982

Appendix table 1-26. U.S. trade balance in selected manufactured product groups: 1960–80

(Dollars in millions)

Product groups	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Chemicals[1]																					
Balance[2]	$ 955	$1,051	$1,104	$1,294	$1,662	$1,634	$1,718	$1,844	$2,158	$2,155	$2,376	$2,224	$2,118	$3,286	$4,801	$4,995	$5,187	$5,842	$6,193	$9,827	$12,157
Export	1,776	1,789	1,876	2,009	2,364	2,403	2,675	2,802	3,287	3,383	3,826	3,836	4,133	5,749	8,819	8,691	9,959	10,812	12,623	17,306	20,740
Import	821	738	772	715	702	769	957	958	1,129	1,228	1,450	1,612	2,015	2,463	4,018	3,696	4,772	4,970	6,430	7,479	8,583
Machinery[3]																					
Balance[2]	3,752	4,179	4,493	4,648	5,211	5,135	4,991	5,180	5,072	5,567	6,311	5,780	5,646	7,438	12,507	17,245	16,667	13,794	13,353	17,384	24,977
Import	4,476	4,968	5,448	5,702	6,525	7,935	7,678	8,279	8,844	10,137	11,685	11,839	13,562	17,588	24,318	29,215	32,113	32,630	38,105	45,914	57,263
Import	724	789	955	1,054	1,314	1,800	2,687	3,099	3,772	4,570	5,374	6,059	7,916	10,150	11,811	11,970	15,446	18,836	24,752	28,530	32,286
Aircraft																					
Balance[2]	970	766	857	726	791	990	824	1,271	2,015	2,140	2,382	3,049	2,580	3,556	3,258	5,617	5,670	5,271	7,601	8,641	10,931
Export	1,024	903	980	817	874	1,130	1,097	1,519	2,309	2,423	2,656	3,387	2,995	4,119	5,766	6,136	6,104	5,874	8,203	9,719	12,816
Import	54	137	123	91	83	140	273	248	294	283	274	338	415	563	508	519	434	603	602	1,078	1,885
Professional and scientific instruments[4]																					
Balance[2]	214	241	266	290	306	389	463	522	530	609	653	674	668	822	1,308	1,487	1,439	2,200	2,451	3,433	4,339
Export	321	358	411	447	504	610	724	807	872	1,012	1,107	1,166	1,313	1,632	2,209	2,397	2,654	4,054	4,977	6,187	7,505
Import	107	117	145	157	198	221	261	285	342	403	454	492	645	810	901	910	1,215	1,854	2,526	2,754	3,166
Autos & parts																					
Balance[2]	643	810	850	955	1,063	934	536	237	–589	–1,104	–1,823	–2,897	–3,492	–3,679	–3,016	–623	–2,972	–4,957	–8,431	–8,149	–10,898
Export	1,270	1,188	1,365	1,518	1,749	1,744	2,154	2,503	3,123	3,514	3,245	3,879	4,473	5,573	7,248	9,290	10,132	10,887	12,148	13,904	13,117
Import	627	378	515	563	686	810	1,618	2,266	3,712	4,618	5,068	6,776	7,965	9,252	10,264	9,913	13,104	15,844	20,579	22,053	24,015

[1]Includes drugs and other allied products.
[2]Exports less imports.
[3]Machinery includes all nonelectrical and electrical, computers and communication equipment. Beginning in 1977, sound recorders, reproducers and accessories are classified in machinery (previously included in other manufactured goods) and photocopy apparatus which had previously been in scientific and professional instruments.
[4]Beginning in 1977, includes electric measuring and controlling instruments which were classified as machinery prior to 1977.

SOURCE: U.S. Department of Commerce, *Overseas Business Reports,* August 1967, April 1972, April 1977, June 1978, August 1979, July 1980 and November 1981.

See figures 1-14 and 1-15.

Appendix table 1-27. U.S. trade balance with selected nations for R & D-intensive manufactured products: 1966–80

(Dollars in millions)

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Developing nations[1]															
Balance[2]	$3,441	$3,677	$4,430	$4,455	$4,928	$5,087	5,277	$6,641	$10,658	$14,726	$16,052	$16,022	$17,942	$23,310	$29,818
Export	3,682	3,923	4,822	5,002	5,679	5,996	6,765	8,966	14,025	17,700	20,104	20,993	24,685	31,510	39,845
Import	241	246	392	547	751	909	1,488	2,325	3,367	2,974	4,052	4,971	6,743	8,200	10,027
Western Europe[3]															
Balance[2]	1,890	2,283	2,566	2,986	3,942	3,599	3,089	4,126	5,982	6,700	7,061	6,918	10,203	10,042	14,584
Export	3,865	4,359	5,020	5,655	6,927	6,861	7,345	9,597	12,621	13,540	14,649	15,712	22,159	24,382	30,849
Import	1,975	2,076	2,454	2,669	2,985	3,262	4,256	5,471	6,639	6,840	7,588	8,794	11,956	14,340	16,265
Canada															
Balance[2]	1,800	1,760	1,719	1,914	1,684	1,865	2,333	3,003	4,242	4,833	4,732	4,530	4,872	5,420	6,283
Export	2,838	2,983	3,142	3,478	3,513	3,914	4,678	5,741	7,419	8,136	8,831	9,182	10,467	12,211	13,520
Import	1,038	1,223	1,423	1,564	1,829	2,049	2,345	2,738	3,177	3,303	4,099	4,652	5,595	6,791	7,237
Japan															
Balance[2]	–133	–115	–200	–324	–224	–516	–971	–848	–550	–1,020	–2,654	–3,460	–5,694	–4,275	–3,563
Export	661	772	930	1,180	1,536	1,520	1,639	2,218	3,007	2,390	2,701	2,792	3,630	5,318	6,255
Import	794	887	1,130	1,504	1,760	2,036	2,610	3,066	3,557	3,410	5,355	6,252	9,324	9,593	9,818
West Germany															
Balance[2]	([4])	([4])	([4])	81	287	190	–56	–204	–211	64	58	–73	–351	–49	216
Export	([4])	([4])	([4])	912	1,277	1,295	1,340	1,579	1,932	2,143	2,346	2,674	3,480	4,299	5,206
Import	([4])	([4])	([4])	831	990	1,105	1,396	1,783	2,143	2,079	2,288	2,747	3,831	4,348	4,990
Communist Areas															
Balance	NA	NA	48	86	87	117	110	326	497	889	799	568	605	845	871
Export	NA	NA	65	103	106	137	140	379	596	978	915	691	807	1,144	1,325
Import	NA	NA	17	17	19	20	30	53	99	89	116	123	202	299	454

[1]Includes the Republic of South Africa in 1966 and 1967.
[2]Exports less imports.
[3]Includes West Germany.
[4]Included in the totals for Western Europe but not separately available.

NOTE: R&D-intensive manufactured goods are those found in appendix table 1-25.

SOURCE: U.S. Department of Commerce, *Overseas Business Reports,* May 1972, June 1974, October 1976, December 1979, October 1980, and November 1982.

See figure 1-16

Appendix table 1-28. Changes in world[1] export shares of all manufactured products and of R&D-intensive products,[2] for selected countries: 1955-80

Country and product group	1955	1960	1970	1980	Change from 1955-80
United States					
All manufactured products	25.9	22.8	18.4	16.4	−9.5
R&D–intensive products	35.5[3]	27.6	23.1	19.9	−15.6
Japan					
All manufactured products	4.8	6.5	8.9	11.0	+6.2
R&D–intensive products	1.8[3]	4.2	9.7	14.5	+12.7
West Germany					
All manufactured products	14.6	18.2	19.8	19.8	+5.2
R&D–intensive products	17.6[3]	21.2	20.4	19.3	+1.7
France					
All manufactured products	8.8	9.1	8.3	10.2	+1.4
R&D–intensive products	6.4[3]	7.7	7.6	9.0	+2.6

[1] "World" exports are defined as the sum of the exports from 14 or 15 most important OECD (industrial) countries. The listed countries' percentages differ very little depending on whether the sum of the 14 or 15 countries is used in the calculation.

[2] Based on DOC1 definition of R&D–intensive products, which includes automobiles as well as the product groups in figure 1-14.

[3] Data are from 1954.

SOURCE: U.S. Department of Commerce, *An Assessment of U.S. Competitiveness in High Technology Industries,* 1983, p. 46.

See figure 1-17.

Science Indicators—1982

Appendix table 1-29. Changes in world export shares[1] by selected product groups: 1970 and 1980

(Percent)

Commodity group	United States 1970	United States 1980	United States Change from 1970–80	Japan 1970	Japan 1980	Japan Change from 1970–80	West Germany 1970	West Germany 1980	West Germany Change from 1970–80	France 1970	France 1980	France Change from 1970–80
Total merchandise trade	15.4	12.0	–3.4	8.9	10.6	1.7	15.7	15.6	–0.1	8.1	9.0	0.9
Total manufactured products	18.4	16.4	–2.0	8.9	11.0	2.1	19.8	19.8	—	9.1	10.2	1.1
High-technology products	29.9	26.1	–3.8	11.9	15.8	3.9	14.6	15.7	1.1	7.2	7.8	.6
Drugs and medicinals	17.1	15.8	–1.3	2.7	2.3	–.4	19.9	17.6	–2.3	9.3	11.6	2.3
Business machines and equipment	37.7	37.0	–.7	8.0	9.9	1.9	15.1	13.0	–2.1	7.8	7.8[2]	—
Computers	31.5	35.5	4.0	11.1	12.3	1.2	11.2	12.1	.9	9.0	7.1	–1.9
Electrical and electronic machines and equipment	21.6	18.0	–3.6	10.3	18.7	8.4	19.5	18.7	–.8	8.1	9.2	1.1
Telecommunications equipment	21.9	18.1	–3.8	11.9	23.1	11.2	15.2	14.6	–.6	5.5	7.7	2.2
Electronic components	39.8	27.6	–12.2	6.3	27.0	20.7	12.5	14.3	1.8	8.6	8.8	.2
Consumer electronics	9.3	9.9	.6	49.0	53.0	4.0	14.3	12.0	–2.3	2.3	5.5	2.2
Jet engines	40.4	32.0	–8.4	.1	.1	—	5.4	5.3	–.1	5.6	7.8	2.2
Aircraft	66.0	53.1	–12.9	.8	.4	–.4	2.9	10.7	7.8	7.6	9.1	1.5
Scientific instruments	29.3	26.8	–2.5	8.7	10.4	1.7	21.5	19.4	–2.1	7.1	8.1	1.0

[1]"World" exports are defined as the sum of the exports from 14 or 15 most important OECD (industrial) countries. The listed countries' percentages differ very little depending on whether the sum of the 14 or 15 countries is used in the calculation.
[2]Average 1979–80.

SOURCE: U.S. Department of Commerce, *An Assessment of U.S. Competitiveness in High-Technology Industries*, 1983, pp. 44–45.

Science Indicators—1982

Appendix table 1-30. U.S.S.R. imports of Western technology: 1970–81

(Dollars in millions)

Sources of high-technology products

Countries	1970 High-tech. exports to USSR	1970 As % of total	1972 High-tech. exports to USSR	1972 As % of total	1979 High-tech. exports to USSR	1979 As % of total	1980 High-tech. exports to USSR	1980 As % of total	1981 High-tech. exports to USSR	1981 As % of total
Total	$402.9	100.0	$329.2	100.0	$2,371.3	100.0	$2,330.0	100.0	$1,735.5	100.0
United States	12.5	3.1	26.8	8.1	154.7	6.5	84.7	3.6	56.5	3.3
Canada	.2	—	.7	.2	11.3	.5	27.5	1.2	.4	—
Japan	43.5	10.8	41.8	12.7	398.9	16.8	400.2	17.2	366.0	21.1
Belgium-Luxemburg	5.9	1.5	4.3	1.3	21.1	.9	18.0	.8	12.1	.7
Denmark	4.8	1.2	4.6	1.4	17.1	.7	23.1	.1	17.9	1.0
France	58.5	14.5	38.0	11.5	376.8	15.9	341.3	14.8	204.7	11.8
West Germany	92.9	23.0	79.4	24.1	668.3	28.2	727.2	31.6	501.8	28.9
Ireland	—	—	—	—	1.3	.1	.2	—	—	—
Italy	69.6	17.3	51.1	15.5	257.2	10.8	222.2	9.6	156.3	9.0
Netherlands	1.1	.3	3.2	1.0	16.7	.7	6.1	.3	10.0	.6
United Kingdom	56.0	13.9	43.4	13.2	94.0	4.0	125.7	5.5	93.6[1]	5.4
Austria	5.6	1.4	4.8	1.5	43.7	1.8	48.2	2.1	30.4	1.8
Finland	6.3	1.6	5.4	1.7	70.9	3.0	86.2	3.7	121.8	7.0
Norway	.1		.2	.1	8.2	.3	12.3	.5	6.5	.4
Sweden	22.3	5.5	9.0	2.7	119.9	5.1	71.1	3.1	77.3	4.5
Switzerland	23.6	5.9	16.3	5.0	111.3	4.7	136.4	5.9	80.0	4.6

Sources of manufactured products

Countries	1970 Manufactured exports to USSR	1970 High-tech. as % of total	1972 Manufactured exports to USSR	1972 High-tech. as % of total	1979 Manufactured exports to USSR	1979 High-tech. as % of total	1980 Manufactured exports to USSR	1980 High-tech. as % of total	1981 Manufactured exports to USSR	1981 High-tech. as % of total
Total	$2,212.4	18.2	$2,726.0	20.3	$13,642.4	17.4	$15,113.1	15.4	$14,435.4	12.0
United States	83.1	15.1	102.4	38.4	656.6	23.6	423.7	20.0	586.0	9.6
Canada	6.3	.3	13.9	9.6	227.8	5.0	169.0	16.3	53.5	.7
Japan	327.7	13.3	492.4	17.7	2,359.5	16.9	2,607.8	15.3	3,091.5	11.8
Belgium-Luxemburg	50.0	11.7	80.1	4.2	414.3	5.1	490.5	3.7	327.5	3.7
Denmark	23.1	20.7	23.7	23.9	60.5	28.3	61.0	37.9	58.4	30.8
France	257.0	22.8	271.9	25.1	1,772.7	21.3	1793.3	19.0	1,179.0	17.4
West Germany	412.6	22.5	699.4	23.4	3,474.5	19.2	3,904.5	18.6	2,877.3	17.4
Ireland	—	—	.6	—	4.5	29.7	4.7	5.4	6.0	.8
Italy	292.3	23.8	256.7	24.0	1,165.0	22.1	1,176.3	18.9	1,151.0	13.6
Netherlands	33.0	3.3	40.8	5.7	169.0	9.9	204.0	3.0	213.9	4.7
United Kingdom	219.5	25.5	202.3	28.1	796.4	11.8	950.9	13.2	908.3	10.3
Austria	78.8	7.1	93.1	9.6	510.9	8.5	445.7	10.8	460.9	6.6
Finland	242.7	2.6	294.9	3.2	1,379.5	5.1	2186.4	3.9	1,957.7	4.1
Norway	20.2	.6	18.5	2.4	80.0	10.3	94.6	13.0	87.5	7.5
Sweden	116.3	19.2	66.3	18.7	306.2	39.2	304.2	23.4	272.0	28.4
Switzerland	49.9	47.3	69.0	46.9	264.6	42.1	296.5	46.0	205.0	39.0

[1]Estimate.

SOURCE: U.S. Department of Commerce, *Quantification of Western Exports of High-Technology Products to Communist Countries*, forthcoming.

Appendix table 1-31. Ratio of receipts to payments of royalties and fees: 1970-81

(Percent)

Year	United States			Total (Affiliated and unaffiliated)		
	Total	Affiliated	Unaffiliated	Japan	West Germany	France
1970	948	1,406	503	13	NA	34
1971	985	1,489	502	13	37	30
1972	873	1,619	471	13	43	30
1973	785	1,105	405	12	36	32
1974	1,036	1,771	404	15	41	40
1975	847	1,132	407	20	39	37
1976	847	1,113	435	22	38	33
1977	1,038	1,474	482	21	36	52
1978	871	1,082	487	24	39	51
1979	752	888	457	25	38	53
1980	868	1,057	478	27	42	48
1981	998	1,289	525	NA	NA	NA

SOURCES: United States: Based on appendix tables 1-33, 1-34, and 1-35.
Other countries: Alan Rapoport and Asim Erdilek, "Technology Transfer as a Key Variable Affecting International Competitiveness," National Science Foundation (in press).

Science Indicators—1982

Appendix table 1-32. Direct investment-related U.S. receipts of royalties and fees[1] by industrial area: 1981

(Dollars in millions)

Country	All industries	Total manufacturing	Food products	Chemicals	P&F[2] metals	Machinery	Electrical machinery	Transportation equipment	Other manufacturing
Total net receipts	$5,867	$4,007	$247	$1,001	$159	$1,140	$429	$337	$694
Developed countries	4,805	3,510	188	881	117	1,106	304	308	606
Canada	980	747	35	104	25	176	44	219	143
Europe	3,035	2,264	112	657	84	736	216	73	387
United Kingdom	832	669	34	197	28	217	31	36	125
West Germany	369	311	17	68	22	107	31	18	49
France	324	327	10	105	25	105	28	7	46
Japan	413	310	27	47	4	175	26	7	25
Developing countries	1,331	497	59	120	42	35	125	28	88

[1] Includes film and tape rentals, which represents 6 percent of total net receipts.
[2] Primary and ferrous metals.

SOURCE: U.S. Department of Commerce, unpublished data, August 19, 1982.

Science Indicators—1982

Appendix table 1-33. U.S. receipts and payments of royalties and fees[1] with selected nations: 1967–81

(Dollars in millions)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 (prel.)
Total net receipts[2]	$1,516	$1,683	$1,842	$2,134	$2,375	$2,566	$3,021	$3,584	$4,008	$4,084	$4,503	$5,312	$5,747	$6,617	$6,917
Developed countries	1,152	1,271	1,404	1,651	1,856	2,031	2,421	2,857	3,177	3,273	4,027	4,547	4,808	5,487	5,625
United Kingdom	208	214	238	273	306	334	376	427	523	520	563	724	821	837	923
European Community[3]	334	383	431	511	585	631	794	954	1,091	1,043	1541	1,515	1,637	1,956	1,795
Other Europe	107	112	135	142	163	188	216	276	337	345	371	482	475	630	712
Canada	275	296	295	344	365	394	426	555	585	651	807	838	892	963	1,009
Japan	132	175	208	268	306	342	426	439	419	485	514	729	711	746	762
ANZSA[4]	86	86	97	113	131	142	183	206	222	222	230	261	272	353	418
Developing countries	365	411	440	483	520	536	599	726	831	813	752	991	1,148	1,418	1,561
Total net payments[5]	166	186	221	225	241	294	385	346	473	482	434	610	764	762	693
Developed countries	163	183	217	216	234	289	376	346	452	451	481	585	731	901	977
United Kingdom	43	56	67	54	48	59	73	84	103	85	91	159	195	304	340
European Community	43	51	54	54	58	63	95	75	84	92	100	190	244	258	164
Other Europe	27	22	27	34	54	93	114	173	135	149	120	143	170	216	235
Canada	46	51	60	66	69	66	79	53	148	146	126	142	179	184	282
Japan	11	7	8	8	5	7	14	–35	–17	–21	–18	–55	–60	–65	–45
ANZSA[4]	14	14	8	14	14	8	8	–4	–1	–1	–1	6	3	4	—
Developing countries	4	4	5	9	7	6	10	–1	20	33	16	24	32	–140	–286

[1]Excludes film rentals which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business.*
[2]Represents net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.
[3]Original six members only.
[4]ANZSA = Australia, New Zealand, and the Republic of South Africa.
[5]Payments measure net transactions between U.S. affiliates and their foreign parents. See footnote 2.

NOTE: Detail may not add to totals because of rounding. Negative payments represent foreign liabilities to U.S.-based affiliates.

SOURCES: Appendix tables 1-34 and 1-35.

See figures 1-18 and 1-19.

Appendix table 1-34. U.S. receipts and payments of royalties and fees[1] associated with foreign direct-investments: 1967–81

(Dollars in millions)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 (prel.)
Total net receipts[2]	$1,123	$1,246	$1,356	$1,561	$1,757	$1,911	$2,309	$2,833	$3,251	$3,262	$3,583	$4,256	$4,645	$5,432	$5,531
Developed countries	809	893	975	1,142	1,299	1,448	1,783	2,200	2,522	2,570	3,237	3,654	3,885	4,517	4,489
United Kingdom	153	161	183	217	240	271	302	356	444	448	481	630	719	732	795
European Community[3]	237	275	297	354	424	473	625	767	892	833	1,315	1,265	1,370	1,687	1,444
Other Europe	78	79	99	104	112	131	157	203	257	258	247	369	355	517	579
Canada	242	265	267	311	333	356	394	517	547	613	765	791	849	903	945
Japan	37	45	53	66	83	102	153	190	200	239	239	385	368	385	389
ANZSA[4]	62	68	76	90	107	115	152	167	182	179	189	216	224	291	347
Developing countries	315	352	382	418	458	464	525	632	729	693	622	828	969	1,203	1,301
Total net payments[5]	62	80	101	111	118	155	209	160	287	293	243	393	523	514	429
Developed countries	62	80	101	108	115	154	208	167	270	267	237	375	497	666	729
United Kingdom	11	21	26	19	11	15	20	17	27	8	19	68	102	224	247
European Community[3]	–3	—	2	2	3	6	23	5	17	25	37	117	164	166	83
Other Europe	11	9	13	21	36	72	91	151	115	132	99	124	141	192	215
Canada	43	47	56	62	64	60	73	46	139	137	118	132	163	166	269
Japan	—	3	4	4	1	1	1	–47	–26	–34	–34	–69	–75	–84	–84
ANZSA[4]	—	—	—	—	—	—	—	–5	–2	–1	–2	3	2	2	–1
Developing countries	1	1	1	2	3	1	1	–9	16	27	4	17	25	–153	–302

[1]Excludes film rentals which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business.*

[2]Represents net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.

[3]Original six members only.

[4]ANZSA = Australia, New Zealand, and the Republic of South Africa.

[5]Payments measure net transactions between U.S. affiliates and their foreign parents. See footnote 2.

NOTE: Detail may not add to totals because of rounding. Negative payments represent foreign liabilities to U.S.-based subsidiaries. Beginning with 1977 (negative) receipts from international organizations are included in the total but are not shown separately.

SOURCES: Meryl L. Kroner, "U.S. International Transactions in Royalties and Fees, 1967–78;" *Survey of Current Business,* vol. 60 (January 1980), p. 34, and U.S. Department of Commerce, unpublished tables.

See appendix table 1-33.

Appendix table 1-35. U.S. receipts and payments of royalties and fees associated with unaffiliated foreign residents[1]: 1967–81

(Dollars in millions)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 (prel.)
Total net receipts[2]	$393	$437	$486	$573	$618	$655	$712	$751	$757	$822	$920	$1,056	$1,102	$1,185	$1,386
Developed countries	343	378	429	509	557	583	638	657	655	703	790	893	923	470	1,126
United Kingdom	55	53	55	56	66	63	74	71	79	72	82	94	103	105	128
European Community[3]	107	113	134	157	161	158	169	187	199	210	226	250	267	269	351
Other Europe	29	33	36	38	51	57	59	73	80	87	124	113	120	113	133
Canada	33	31	28	33	32	38	32	38	38	45	42	47	43	60	64
Japan	95	130	155	202	223	240	273	249	219	246	275	344	343	361	379
ANZSA[4]	24	18	21	23	24	27	31	39	40	43	41	45	48	62	71
Developing countries	50	59	58	65	62	72	74	94	102	120	130	163	179	215	260
Total net payments[5]	104	106	120	114	123	139	176	186	186	189	191	217	241	248	264
Developed countries	101	103	116	108	119	135	168	179	182	184	181	210	234	235	248
United Kingdom	32	35	41	35	37	44	53	67	76	77	72	91	93	80	93
European Community[3]	46	47	52	52	55	57	72	70	67	67	63	73	80	92	81
Other Europe	16	13	14	13	18	21	23	22	20	17	21	19	29	24	20
Canada	3	4	4	4	5	6	6	7	9	9	8	10	16	18	14
Japan	4	4	4	4	4	6	13	12	9	13	16	14	15	19	39
ANZSA[4]	—	—	1	—	—	1	1	1	1	1	1	3	1	2	1
Developing countries	3	3	4	7	4	5	9	8	4	6	12	7	7	13	16

[1]Excludes film rentals which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business*.

[2]Represents net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.

[3]Original six members only (Belgium, France, West Germany, Italy, Luxemburg and the Netherlands).

[4]ANZSA = Australia, New Zealand, and the Republic of South Africa.

[5]Payments measure net transactions between U.S. affiliates and their foreign parents. See footnote 2.

NOTE: Detail may not add to totals because of rounding.

SOURCES: Meryl L. Kroner, "U.S. International Transactions in Royalties and Fees, 1967–78;" *Survey of Current Business,* vol. 60 (January 1980), p. 25, and U.S. Department of Commerce, unpublished tables.

See appendix table 1-33.

Appendix table 1-36. Transfers of innovations by U.S.-based multinational enterprises to their manufacturing subsidiaries abroad by R&D intensity of the parent: 1945-77 period

Innovations classified by R&D expenditures of parent	Number of innovations[1]	Percentage transferred abroad, by number of years between U.S. introduction and initial transfer: Less than 2 years after	2 to 3 years after	4 to 5 years after	6 to 9 years after	10 or more years after	Total	Average annual transfer rate from year of first foreign introduction to: 3rd year there-after	1977 year end
	Parent's R&D expenditures as percent of sales								
Under 2 percent	108	22.2	12.1	15.7	13.0	14.7	77.7	0.803	0.349
2 to 3 percent	190	14.7	16.3	10.0	16.3	21.6	78.9	1.003	.293
4 percent and over	108	22.2	20.4	11.1	13.0	22.2	88.9	1.067	.331
	Parent's R&D expenditures as percent of sales, normalized by parent industry								
Under 100 percent	152	13.8	12.5	11.8	23.0	17.8	78.9	.777	.302
100 to 199 percent	123	17.1	17.1	15.5	16.3	13.0	79.0	1.000	.302
200 percent and over	131	26.0	19.8	8.4	21.3	10.0	85.5	1.297	.382
Total	406	18.7	16.3	11.6	14.3	20.2	81.1	1.017	.326

[1] Transfers of 406 innovations by 57 U.S.-based multinational enterprises.

SOURCE: Raymond Vernon and W.H. Davidson, *Foreign Production of Technology-Intensive Products by U.S.-Based Multinational Enterprises*, National Science Foundation, 1979, p. 55.

Science Indicators—1982

Appendix tables 1-37. U.S. direct investment abroad in manufacturing for selected nations and industry groups: 1966–81

(Dollars in millions)

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
All countries[1]	$20,740	$22,803	$25,160	$28,332	$31,049	$34,359	$38,325	$44,370	$51,172	$55,886	$61,161	$62,019	$69,669	$78,640	$89,161	$92,480
Chemical products	3,840	4,541	5,068	5,539	5,865	6,519	7,253	8,415	10,172	11,107	12,183	11,864	13,989	16,578	18,888	20,000
Machinery	5,033	5,455	5,986	7,012	7,842	8,930	10,096	11,811	13,992	15,595	17,091	11,223	13,007	20,924	23,371	24,293
Developed countries[1]	17,214	18,912	20,721	23,285	25,572	28,320	31,558	36,550	41,973	45,427	49,766	50,494	56,292	63,518	71,385	73,163
Chemical products	2,857	3,396	3,803	4,164	4,419	4,959	5,500	6,488	7,821	8,471	9,295	8,990	10,536	13,031	14,456	15,380
Machinery	4,473	4,866	5,317	6,223	6,931	7,907	8,917	10,259	12,003	13,231	14,338	10,189	11,792	17,911	19,870	20,353
Canada[1]	6,697	7,059	7,535	8,404	8,971	9,504	10,491	11,755	13,450	14,691	15,965	14,795	15,736	17,392	18,877	19,659
Chemical products	1,058	1,146	1,222	1,297	1,320	1,453	1,583	1,767	2,049	2,268	2,462	2,249	2,577	2,966	3,402	3,721
Machinery	1,345	1,424	1,508	1,743	1,773	1,891	2,111	2,325	2,682	3,042	3,246	1,552	1,736	2,896	3,161	3,609
All Western Europe[1]	8,906	9,867	10,940	12,372	13,819	15,628	17,529	20,777	23,990	26,013	28,788	30,470	34,655	39,403	45,333	45,533
Chemical products	1,523	1,793	2,058	2,271	2,451	2,792	3,146	3,818	4,757	5,161	5,756	5,698	6,745	8,646	9,551	9,964
Machinery	2,681	2,930	3,226	3,829	4,383	5,097	5,727	6,743	7,971	8,774	9,550	7,299	8,450	12,934	14,382	14,169
France[1]	1,162	1,260	1,303	1,464	1,812	2,107	2,441	2,943	3,428	3,844	3,997	4,210	4,676	5,128	5,916	5,500
Chemical products	164	215	226	266	299	330	390	453	543	592	638	692	755	919	1,049	1,017
Machinery	443	443	456	503	620	744	834	1,011	1,194	1,415	1,405	1,579	1,835	2,207	2,610	2,392
United Kingdom[1]	3,568	3,751	4,159	4,492	4,909	5,427	5,779	6,611	7,371	7,555	7,734	8,310	9,483	11,425	8,618	13,359
Chemical products	591	608	632	644	702	819	870	1,042	1,221	1,262	1,327	1,167	1,461	2,010	2,139	2,175
Machinery	1,049	1,146	1,197	1,412	1,590	1,744	1,853	2,008	2,293	2,405	2,500	1,973	2,194	3,278	3,739	3,901
Germany[1]	1,748	1,956	2,149	2,581	2,675	3,107	3,637	4,442	4,814	5,328	6,706	7,264	8,348	8,575	9,657	10,312
Chemical products	179	200	239	259	295	373	425	578	691	770	915	861	1,162	1,394	1,500	1,644
Machinery	526	583	692	906	976	1,172	1,388	1,683	1,949	2,101	2,436	1,973	2,328	3,205	3,390	3,215
Japan[1]	366	442	527	645	768	978	1,185	1,399	1,520	1,557	1,691	1,968	2,343	2,775	2,972	3,276
Chemical products	87	103	131	161	180	209	244	301	327	360	374	465	544	670	700	781
Machinery	222	266	([2])	([2])	([2])	511	633	732	775	787	862	852	1,075	1,245	1,343	1,416
Developing countries[1]	3,525	3,891	4,439	5,047	5,477	6,038	6,767	7,820	9,200	10,459	11,395	11,545	13,377	15,122	17,774	19,316
Chemical products	983	1,145	1,264	1,375	1,446	1,561	1,753	1,927	2,351	2,636	2,888	2,874	3,453	3,847	4,432	4,620
Machinery	560	589	669	789	910	1,023	1,178	1,552	1,989	2,364	2,752	1,034	1,215	3,013	3,499	3,940

[1] Total manufacturing.
[2] These data are withheld by the U.S. Commerce Department to avoid disclosure of data for individual companies.

SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, *Selected Data on U.S. Direct Investment Abroad, 1966–78,* 1980, and *Survey of Current Business,* (February 1981), pp. 50–51, *Survey of Current Business* (August 1981), p. 31–32, and *Survey of Current Business* (August 1982), pp.21–22.

Science Indicators—1982

Appendix table 1-38. Distribution of foreign students with percentage of all foreign students by field of study, for selected years: 1954/55–1981/82

Field of study	1954/55		1959/60		1964/65		1969/70		1975/76		1978/79		1979/80		1980/81		1981/82	
	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent	Number of students	Percent
Engineering	7,618	22.3	11,279	23.3	18,084	22.0	29,731	22.0	42,000	23.4	76,030	28.8	76,950	26.9	80,470	25.8	75,220	23.1
Business/management	2,953	8.6	4,114	8.5	7,116	8.7	15,587	11.6	28,670	16.0	43,500	16.5	46,960	16.4	54,380	17.4	59,420	18.2
Natural and life sciences	3,681	10.7	6,261	12.9	11,731	14.3	17,006	12.6	23,910	13.3	24,190	9.2	21,880	7.6	23,030	7.4	24,870	7.6
Social sciences	5,041	14.7	6,782	14.0	12,609	15.4	17,272	12.8	20,730	11.6	23,360	8.9	22,530	7.9	24,310	7.8	25,200	7.7
Education	1,457	4.3	2,483	5.1	3,999	4.9	7,779	5.8	9,790	5.5	14,790	5.6	12,340	4.3	11,980	3.8	12,410	3.8
Mathematics and computer science	436	1.3	1,015	2.1	2,670	3.3	4,400	3.3	9,060	5.1	14,740	5.6	15,390	5.4	19,180	6.1	22,620	6.9
Fine and applied arts	1,997	5.8	2,417	5.0	3,946	4.8	6,297	4.7	8,320	4.6	14,120	5.3	14,350	5.0	15,450	5.0	15,190	4.7
Humanities	5,502	16.1	6,829	14.1	12,137	14.8	20,211	14.9	15,030	8.4	14,960	5.7	11,340	4.0	13,070	4.2	12,810	3.9
Health professions	3,184	9.3	3,685	7.6	4,918	6.0	5,969	4.4	7,180	4.0	12,470	4.7	10,950	3.8	11,320	3.6	11,570	3.5
Agriculture	1,199	3.5	1,615	3.3	3,211	3.9	3,667	2.7	5,270	2.9	8,710	3.3	8,750	3.1	8,660	2.8	8,880	2.7
Other	1,164	3.4	2,006	4.1	1,624	1.9	7,040	5.2	9,380	5.2	17,070	6.4	44,900	15.7	50,030	16.1	58,109	17.8
Total	34,232	100.0	48,486	100.0	82,045	100.0	134,959	100.0	179,340	100.0	263,940	100.0	286,340	100.0	311,880	100.0	326,299	100.0

[1]After 1978/79 includes students in a new category called Intensive English Language.
[2]Includes undeclared majors.

SOURCE: *Open Doors: 1978/79* (Washington D.C.: Institute of International Education, 1980), pp. 18–19, *Open Doors 1980/81*, p. 16, and *Open Doors 1981/82*.

See figure 1-20.

Appendix table 1-39. Doctoral degrees[1] awarded to foreign students as a percent of all doctoral degrees from U.S. universities by field: 1959-81[2]

Field	1959	1963	1967	1971	1975	1979	1981
All fields	11.7	12.3	14.0	14.4	16.2	16.1	17.2
Science and engineering	14.8	15.5	17.5	18.7	22.1	21.1	22.1
Physical sciences	12.6	14.0	15.7	16.7	22.9	21.0	22.0
Physics and astronomy	14.9	14.5	16.9	18.6	27.6	25.7	26.1
Chemistry	10.5	12.2	14.6	15.6	19.8	19.7	21.2
Earth sciences[3]	17.1	19.9	17.2	14.6	22.1	16.6	17.1
Mathematical sciences	13.4	15.2	14.6	17.5	24.3	25.5	30.8
Mathematics	NA	NA	NA	NA	NA	26.7	33.7
Computer sciences	NA	NA	NA	NA	NA	21.3	26.3
Engineering	24.5	20.8	23.7	29.8	42.1	46.8	51.5
Life sciences	17.6	17.5	19.6	18.2	19.5	16.5	19.8
Biological sciences	15.5	16.5	16.2	14.3	14.9	12.1	11.1
Agriculture and forestry	24.9	21.0	32.4	33.6	37.4	35.2	37.6
Social sciences	10.7	11.6	13.5	13.7	13.7	12.9	13.0
Psychology	5.5	4.0	4.4	5.6	5.8	4.0	3.9
Other social sciences	15.5	17.6	19.9	19.3	20.2	22.4	24.0
Nonscience total	6.0	6.5	7.4	8.0	8.7	10.1	11.0

[1] Percent of those whose citizenship is known.
[2] Fiscal year of doctorate.
[3] Includes oceanography.

NA = Not available.

SOURCE: National Science Foundation, *Doctorate Record File, Special Tabulations*, unpublished data.

See figure 1-21.

Science Indicators—1982

Appendix table 1-40. Index of international cooperative research[1] by field: 1973-80

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980
	Internationally co-authored articles as a percent of all institutionally co-authored articles							
All fields	12.7	13.3	14.0	14.8	15.1	15.4	16.1	16.3
Clinical medicine	6.6	6.9	6.8	7.8	7.5	7.7	8.1	8.1
Biomedicine	13.7	14.2	15.2	15.7	16.3	16.4	16.9	17.1
Biology	15.5	13.6	15.4	17.0	17.0	17.9	18.6	18.3
Chemistry	16.3	17.2	17.7	18.1	20.7	20.0	21.5	21.8
Physics	22.7	23.7	25.4	25.9	27.5	29.4	27.8	30.2
Earth and space sciences	23.1	22.5	24.6	27.7	27.5	28.7	28.7	30.7
Engineering and technology	13.2	14.0	15.5	14.0	16.2	17.2	18.2	18.2
Mathematics	34.3	39.5	39.8	38.6	37.9	38.8	40.0	42.5
	Internationally co-authored articles							
All fields	8,420	9,113	9,737	10,559	11,338	12,317	13,225	14,057
Clinical medicine	1,881	2,013	1,989	2,314	2,440	2,709	2,837	3,032
Biomedicine	1,454	1,581	1,775	1,862	2,032	2,156	2,395	2,533
Biology	723	655	779	853	915	1,007	1,116	1,051
Chemistry	1,088	1,241	1,286	1,384	1,546	1,600	1,763	1,932
Physics	1,570	1,757	1,933	2,142	2,320	2,548	2,758	2,960
Earth and space sciences	647	658	698	830	849	956	1,021	1,108
Engineering and technology	584	650	720	626	721	806	803	842
Mathematics	473	558	557	548	515	535	532	600
	All institutionally co-authored articles							
All fields	66,105	68,529	69,579	71,220	75,283	79,955	81,894	86,115
Clinical medicine	28,617	28,974	29,078	29,564	32,643	35,160	35,097	37,250
Biomedicine	10,648	11,117	11,683	11,845	12,436	13,116	14,144	14,807
Biology	4,660	4,829	5,073	5,024	5,405	5,620	5,985	5,744
Chemistry	6,694	7,224	7,264	7,632	7,485	7,996	8,185	8,856
Physics	6,897	7,410	7,601	8,271	8,433	8,661	9,179	9,792
Earth and space sciences	2,798	2,920	2,832	2,994	3,085	3,335	3,553	3,615
Engineering and technology	4,412	4,642	4,647	4,470	4,437	4,689	4,421	4,638
Mathematics	1,379	1,413	1,401	1,420	1,359	1,378	1,330	1,413

[1] Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations. This index is based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2] See appendix table 1-13 for the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 1-22.

Science Indicators—1982

Appendix table 1-41. Index of international cooperative research[1] for selected countries: 1973-80

Country[2]	1973	1974	1975	1976	1977	1978	1979	1980
	Internationality co-authored articles as a percent of all institutionally co-authored articles							
West Germany	35.6	37.3	38.2	40.6	41.3	41.6	43.8	46.2
United Kingdom	35.3	37.0	37.7	39.6	40.7	40.2	40.4	41.8
Canada	37.0	38.0	37.3	38.5	38.4	39.4	39.9	40.0
France	26.7	26.9	29.8	31.4	32.5	33.5	33.9	34.0
U.S.S.R.	9.6	10.9	13.3	14.2	17.3	16.3	20.1	19.9
United States	14.0	14.3	15.0	15.9	15.9	15.7	16.6	16.9
Japan	16.4	16.4	16.1	15.2	15.9	15.5	16.3	16.4
	Internationally co-authored articles							
West Germany	1,283	1,527	1,568	1,741	1,923	2,176	2,244	2,459
United Kingdom	2,029	2,219	2,364	2,574	2,633	2,784	2,889	3,159
Canada	1,302	1,369	1,422	1,532	1,599	1,715	1,812	1,819
France	1,131	1,209	1,460	1,591	1,769	1,837	2,003	2,153
U.S.S.R.	288	318	380	432	523	528	604	637
United States	4,807	5,037	5,254	5,675	5,972	6,248	6,755	7,192
Japan	472	495	543	555	635	678	767	872
	All institutionally co-authored articles							
West Germany	3,605	4,093	4,108	4,287	4,654	5,228	5,128	5,324
United Kingdom	5,749	6,002	6,268	6,501	6,473	6,925	7,159	7,553
Canada	3,521	3,604	3,809	3,976	4,166	4,358	4,543	4,542
France	4,233	4,492	4,901	5,065	5,445	5,491	5,902	6,341
U.S.S.R.	3,011	2,926	2,860	3,033	3,031	3,233	3,005	3,199
United States	34,364	35,338	35,100	35,799	37,618	39,768	40,784	42,508
Japan	2,881	3,018	3,363	3,657	3,984	4,386	4,696	5,308

[1] Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations. This index is based on the articles notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] When an article is authored by scientists and engineers from more than one country, that article is counted once for each country involved.

SOURCE: Computer Horizons Inc., unpublished data.

See figure 1-23.

Appendix table 1-42. Distribution of scientific and technical articles[1] in U.S. and foreign journals by field: 1973-80

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980
	U.S. articles[3] in foreign journals[4]							
All fields	19,157	19,176	18,913	19,463	19,373	20,365	20,080	20,644
Clinical medicine	4,695	4,850	5,000	4,854	4,975	5,384	5,268	5,118
Biomedicine	4,124	4,092	4,098	4,544	4,306	4,720	4,896	4,817
Biology	1,660	1,711	1,999	2,180	2,049	2,006	2,037	2,026
Chemistry	2,346	2,342	2,107	1,970	2,018	2,168	2,036	2,321
Physics	2,661	2,702	2,513	2,516	2,742	2,535	2,525	2,853
Earth and space sciences	1,200	1,131	996	1,109	1,126	1,152	1,179	1,176
Engineering and technology	1,382	1,338	1,195	1,255	1,302	1,565	1,351	1,557
Mathematics	1,089	1,010	1,005	1,035	855	835	768	771
	Foreign articles in U.S. journals							
All fields	28,425	28,902	30,425	32,502	33,058	33,860	36,353	36,161
Clinical medicine	6,794	6,867	6,882	7,560	7,923	8,398	8,898	9,283
Biomedicine	4,148	4,340	5,144	5,154	5,377	5,158	5,493	5,584
Biology	2,013	1,889	1,865	1,803	1,971	2,296	2,587	2,417
Chemistry	5,484	5,700	6,270	7,062	6,583	6,252	6,769	6,703
Physics	4,118	4,384	4,434	5,048	5,143	5,556	6,095	6,144
Earth and space sciences	1,284	1,204	1,108	1,170	1,146	1,283	1,251	1,280
Engineering and technology	3,723	3,611	3,748	3,618	3,848	3,904	4,241	3,792
Mathematics	861	907	974	1,087	1,067	1,013	1,019	958
	Balance[5]							
All fields	9,263	9,726	11,512	13,039	13,685	13,495	16,293	15,517
Clinical medicine	2,099	2,017	1,882	2,706	2,948	3,014	3,630	4,165
Biomedicine	24	248	1,046	610	1,071	438	597	767
Biology	353	178	–134	–377	–78	290	550	391
Chemistry	3,138	3,358	4,163	5,092	4,565	4,084	4,733	4,382
Physics	1,457	1,682	1,921	2,532	2,401	3,021	3,570	3,291
Earth and space sciences	84	73	112	61	20	131	72	104
Engineering and technology	2,341	2,273	2,553	2,363	2,546	2,339	2,890	2,235
Mathematics	–228	–103	–31	52	212	178	251	187

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see Appendix table 1-12.

[2] See Appendix table 1-13 for a description of the subfields included in these fields.

[3] When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States, it is split to these countries on the basis of the number of organizations represented by these authors.

[4] The country of a journal is determined by where it is published.

[5] When the balance is negative, more U.S. articles are being published in journals abroad than foreign articles in U.S. journals. When the balance is positive, the United States is publishing more foreign articles than U.S. researchers are publishing abroad.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 1-43. U.S. use of other nations' research literature compared to all foreign usage by field: 1973 and 1980

Field[1]		United Kingdom 1973	United Kingdom 1980	West Germany 1973	West Germany 1980	France 1973	France 1980	USSR 1973	USSR 1980	Japan 1973	Japan 1980	Canada 1973	Canada 1980
		Relative citation index[2]											
All fields	U.S. use	NA	1.06	NA	0.73	NA	0.67	NA	0.15	NA	0.71	NA	1.07
	Foreign use[3]	NA	1.10	NA	.85	NA	.74	NA	.20	NA	.74	NA	.99
Clinical medicine	U.S. use	1.06	1.03	.29	.44	.30	.44	.06	.05	.56	.71	1.13	1.06
	Foreign use	1.12	1.13	.43	.55	.37	.49	.07	.07	.57	.72	1.05	.98
Biomedicine	U.S. use	1.17	.94	.60	.85	.46	.67	.09	.12	.78	.84	.97	1.00
	Foreign use	1.20	.98	.67	.94	.50	.70	.11	.13	.78	.85	.93	.98
Biology	U.S. use	.95	.94	.57	.70	.43	.78	([4])	([4])	.44	.49	.93	1.04
	Foreign use	1.11	1.06	.72	.84	.56	.92	([4])	([4])	.48	.56	.85	.94
Chemistry	U.S. use	1.42	1.46	1.20	1.20	.67	1.00	.14	.16	.59	.79	1.46	1.37
	Foreign use	1.35	1.46	1.33	1.27	.69	1.01	.17	.19	.56	.73	1.25	1.21
Physics	U.S. use	.96	1.10	.98	1.07	.88	.89	.30	.29	.63	.82	1.25	1.25
	Foreign use	.93	1.10	.99	1.05	.87	.89	.31	.34	.64	.80	1.14	1.15
Earth and space sciences	U.S. use	1.07	.91	.73	.75	.58	.69	.20	.18	.62	.85	1.01	.97
	Foreign use	1.11	.93	.80	.82	.66	.75	.22	.22	.66	.87	.96	.93
Engineering and technology	U.S. use	1.01	.93	.46	.53	.74	.77	.15	.18	.64	.93	1.21	.97
	Foreign use	.95	.96	.62	.63	.70	.82	.18	.21	.59	.88	1.01	.87
Mathematics	U.S. use	1.15	1.14	.72	.59	.59	.69	.92	.39	.60	.60	.81	1.10
	Foreign use	1.09	1.06	.82	.64	.84	.75	.89	.46	.73	.62	.77	1.01
		U.S. use compared to world use (in percent)[2]											
All fields		NA	-4	NA	-14	NA	-9	NA	-25	NA	-4	NA	+8
Clinical medicine		-5	-9	-33	-20	-19	-10	-14	-29	-2	-1	+8	+8
Biomedicine		-3	-4	-10	-10	-8	-4	-18	-8	same	-1	+4	+2
Biology		-14	-11	-21	-17	-23	-15	([4])	([4])	-8	-12	+9	+11
Chemistry		+5	same	-10	-6	-3	-1	-18	-16	+5	+8	+17	+13
Physics		+3	same	-1	+2	-1	same	-3	-15	-2	+3	+10	+9
Earth and space sciences		-4	-2	-9	-9	-12	-8	-9	-18	-6	-2	+5	+4
Engineering and technology		+6	-3	-26	-16	+6	-6	-17	-14	+8	+6	+20	+11
Mathematics		+6	+8	-12	-8	-30	-8	+3	-15	-18	-3	+5	+9

[1] See appendix table 1-13 for a description of the subfields included in these fields.

[2] An index of 1.00 reflects no over- or under-citing of a country's research literature. It is defined as the ratio of a country's share of all the world's citations in a field to the share of its publications in that field. For example, in 1980, U.S. researchers used 20 percent more of the West German chemical research literature than could have been accounted for by the West German share of all chemical research articles in this journal set.

[3] These "foreign use" relative citation indexes do not include citations from articles authored by researchers from the country being cited.

[4] Cannot be calculated since the U.S.S.R. biology articles in this set of journals is less than two percent of the world total.

[5] These percentages show how the United States differs in its use of other nations' research compared to all foreign use of a country's research literature.

NOTE: Based on the articles, notes and reviews in over 2,100 of the influential journals on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-11 in text.

Science Indicators—1982

Appendix table 2-1. Gross national product price deflators used in the calculation of 1972 constant dollars throughout this report: 1960-83

Year	Calendar year GNP price deflator	Fiscal year GNP price deflator
1960	0.6870	0.6957
1961	.6933	.7036
1962	.7061	.7137
1963	.7167	.7256
1964	.7277	.7338
1965	.7436	.7498
1966	.7676	.7696
1967	.7906	.7944
1968	.8254	.8231
1969	.8679	.8617
1970	.9145	.9104
1971	.9601	.9562
1972	1.0000	1.0000
1973	1.0575	1.0445
1974	1.1508	1.1206
1975	1.2579	1.2326
1976	1.3234	1.3188
1977	1.4005	1.4076
1978	1.5042	1.5033
1979	1.6342	1.6346
1980	1.7864	1.7782
1981	1.9551	1.9528
1982	2.0722	2.0902
1983	2.1809	2.1945

NOTE: Calendar year deflators were taken directly from sources cited below. Fiscal year deflators were calculated from quarterly data in the same sources.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* and *Commerce News.*

Science Indicators—1982

Appendix table 2-2. National R&D expenditures by source as a percent of GNP: 1960-83

(Dollars in billions)

Year	Current dollars				Constant 1972 dollars[1]				As a percent of GNP		
	GNP	Total	Federal	Other	GNP	Total	Federal	Other	Total	Federal	Other
1960	$ 506.5	$13.5	$ 8.7	$ 4.8	$ 737.3	$19.6	$12.7	$ 7.0	2.67	1.72	0.95
1961	524.6	14.3	9.3	5.0	756.7	20.6	13.3	7.3	2.73	1.77	.95
1962	565.0	15.4	9.9	5.5	800.2	21.8	14.0	7.8	2.73	1.75	.97
1963	596.7	17.1	11.2	5.9	832.6	23.7	15.6	8.2	2.86	1.88	.99
1964	637.7	18.9	12.5	6.3	876.3	25.9	17.2	8.7	2.96	1.96	.99
1965	691.1	20.0	13.0	7.0	929.4	26.9	17.4	9.5	2.90	1.88	1.01
1966	756.0	21.8	14.0	7.9	984.9	28.4	18.2	10.3	2.88	1.85	1.05
1967	799.6	23.1	14.4	8.8	1,011.4	29.2	18.2	11.1	2.90	1.80	1.10
1968	873.4	24.6	14.9	9.7	1,058.2	29.8	18.1	11.7	2.82	1.71	1.11
1969	944.0	25.6	14.9	10.7	1,087.7	29.6	17.2	12.4	2.72	1.58	1.13
1970	992.7	26.1	14.9	11.3	1,085.5	28.6	16.3	12.3	2.63	1.50	1.14
1971	1,077.6	26.7	15.0	11.8	1,122.4	27.8	15.6	12.2	2.48	1.39	1.10
1972	1,185.9	28.5	15.8	12.6	1,185.9	28.5	15.8	12.7	2.40	1.33	1.06
1973	1.326.4	30.7	16.4	14.4	1,254.3	29.2	15.6	13.6	2.32	1.24	1.09
1974	1.434.2	32.9	16.9	16.0	1,246.3	28.8	14.8	14.0	2.29	1.18	1.12
1975	1,549.2	35.2	18.1	17.1	1,231.6	28.2	14.5	13.7	2.27	1.17	1.10
1976	1,718.0	39.0	19.9	19.1	1,298.2	29.5	15.1	14.4	2.27	1.15	1.11
1977	1,918.3	42.8	21.6	21.2	1,369.7	30.5	15.4	15.1	2.23	1.13	1.11
1978	2,163.9	48.2	23.9	24.3	1,438.6	32.0	15.9	16.1	2.22	1.11	1.12
1979	2,417.8	55.0	26.9	28.1	1,479.5	33.6	16.4	16.2	2.28	1.11	1.16
1980	2,633.1	62.7	29.7	33.0	1,474.0	35.2	16.7	18.5	2.38	1.13	1.25
1981 (prelim.)	2,937.7	72.1	33.8	38.3	1,502.6	36.9	17.3	19.6	2.45	1.15	1.30
1982 (est.)	3,057.6	79.0	36.6	42.4	1,475.5	38.1	17.6	20.5	2.58	1.20	1.39
1983 (est.)	3,262.0	86.5	39.6	46.9	1,495.7	39.6	18.1	21.5	2.65	1.21	1.44

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Percents are calculated from unrounded figures. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data, and U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* and *Commerce News.*

See figures 2-1, 2-2, 2-3, and 2-4.

Science Indicators—1982

Appendix table 2-3. National expenditures for R&D source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities and colleges[1]	Other nonprofit institutions
			Current dollars		
1960	$13,523	$ 8,738	$ 4,516	$ 149	$120
1961	14,316	9,250	4,757	165	144
1962	15,394	9,911	5,123	185	175
1963	17,059	11,204	5,456	207	192
1964	18,854	12,537	5,887	235	195
1965	20,044	13,012	6,548	267	217
1966	21,846	13,968	7,328	304	246
1967	23,146	14,395	8,142	345	264
1968	24,605	14,928	9,005	390	282
1969	25,631	14,895	10,010	420	306
1970	26,134	14,892	10,444	461	337
1971	26,676	14,964	10,822	529	361
1972	28,477	15,808	11,710	574	385
1973	30,718	16,399	13,293	613	413
1974	32,864	16,850	14,878	677	459
1975	35,213	18,109	15,820	749	535
1976	39,016	19,914	17,694	808	600
1977	42,829	21,642	19,629	887	671
1978	48,184	23,933	22,450	1,035	766
1979	54,972	26,860	26,081	1,194	837
1980	62,734	29,716	30,771	1,314	933
1981 (prelim.)	72,118	33,752	35,897	1,512	957
1982 (est.)	79,000	36,610	39,955	1,540	895
1983 (est.)	86,500	39,625	44,285	1,615	975
			Constant 1972 dollars[2]		
1960	$19,635	$12,673	$ 6,573	$ 214	$175
1961	20,584	13,282	6,861	235	206
1962	21,750	13,989	7,256	259	246
1963	23,733	15,570	7,611	285	267
1964	25,857	17,179	8,090	320	268
1965	26,896	17,443	8,806	356	291
1966	28,442	18,180	9,547	395	320
1967	29,241	18,176	10,299	434	332
1968	29,833	18,108	10,910	474	341
1969	29,586	17,209	11,536	488	353
1970	28,613	16,316	11,421	506	370
1971	27,814	15,615	11,271	553	375
1972	28,477	15,808	11,710	574	385
1973	29,147	15,594	12,572	588	393
1974	28,763	14,826	12,930	604	403
1975	28,153	14,537	12,579	608	429
1976	29,508	15,072	13,370	612	454
1977	30,539	15,416	14,016	630	477
1978	32,039	15,916	14,926	688	509
1979	33,637	16,435	15,959	731	512
1980	35,159	16,672	17,225	739	523
1981 (prelim.)	36,900	17,274	18,361	774	491
1982 (est.)	38,048	17,601	19,280	737	430
1983 (est.)	39,605	18,119	20,305	736	445

[1] Includes State and local government sources.

[2] GNP implicit deflators used to convert current dollars to constant 1972 dollars.

NOTE: Detail may not add totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figures 2-5 and 2-13.

Appendix table 2-4. National expenditures for R&D by performer: 1960-83

(Dollars in millions)

Year	Total	Federal intramural laboratories	Industry[1]	Universities and colleges[2]	FFRDC's[3]	Other nonprofit institutions[1]
1960	$13,523	$1,726	$10,509	$ 646	$ 360	$ 282
1961	14,316	1,874	10,908	763	410	361
1962	15,394	2,098	11,464	904	470	458
1963	17,059	2,279	12,630	1,081	530	539
1964	18,854	2,838	13,512	1,275	629	600
1965	20,044	3,093	14,185	1,474	629	663
1966	21,846	3,220	15,548	1,715	630	733
1967	23,146	3,396	16,385	1,921	673	771
1968	24,605	3,494	17,429	2,149	719	814
1969	25,631	3,503	18,308	2,225	725	870
1970	26,134	4,079	18,067	2,335	737	916
1971	26,676	4,228	18,320	2,500	716	912
1972	28,477	4,590	19,552	2,630	753	952
1973	30,718	4,762	21,249	2,884	817	1,006
1974	32,864	4,911	22,887	3,023	865	1,178
1975	35,213	5,354	24,187	3,409	987	1,276
1976	39,016	5,769	26,997	3,727	1,147	1,376
1977	42,829	6,060	29,825	4,065	1,384	1,495
1978	48,184	6,870	33,304	4,621	1,717	1,672
1979	54,972	7,463	38,226	5,354	1,935	1,994
1980	62,734	7,769	44,505	6,050	2,235	2,175
1981 (prelim.)	72,118	8,729	51,830	6,793	2,476	2,290
1982 (est.)	79,000	9,250	57,850	7,010	2,540	2,350
1983 (est.)	86,500	9,750	64,250	7,400	2,600	2,500
	Constant 1972 dollars[4]					
1960	$19,635	$2,481	$15,297	$ 928	$ 517	$ 412
1961	20,584	2,664	15,733	1,085	582	520
1962	21,750	2,940	16,237	1,266	659	648
1963	23,733	3,140	17,622	1,489	730	752
1964	25,857	3,868	18,569	1,738	857	825
1965	26,896	4,124	19,077	1,965	838	892
1966	28,442	4,183	20,256	2,229	819	955
1967	29,241	4,276	20,725	2,417	848	975
1968	29,833	4,246	21,116	2,612	874	985
1969	29,586	4,065	21,094	2,582	842	1,003
1970	28,613	4,481	19,756	2,564	809	1,003
1971	27,814	4,422	19,081	2,613	749	949
1972	28,477	4,590	19,552	2,630	753	952
1973	29,147	4,559	20,094	2,763	781	950
1974	28,763	4,383	19,889	2,696	772	1,023
1975	28,153	4,344	19,229	2,766	801	1,013
1976	29,508	4,374	20,400	2,826	870	1,033
1977	30,539	4,305	21,297	2,888	983	1,066
1978	32,039	4,569	22,142	3,073	1,142	1,113
1979	33,637	4,565	23,391	3,276	1,184	1,221
1980	35,159	4,369	24,914	3,402	1,257	1,217
1981 (prelim.)	36,900	4,470	26,511	3,480	1,268	1,171
1982 (est.)	38,048	4,426	27,918	3,354	1,216	1,134
1983 (est.)	39,605	4,442	29,461	3,371	1,185	1,146

[1] Expenditures for federally funded research and development centers administered by industry and by nonprofit institutions are included in the totals of the respective sectors.

[2] Includes State and local government sources.

[3] Federally funded research and development centers administered by universities.

[4] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figure 2-8.

Appendix table 2-5. National R&D expenditures by character of work: 1960-83

(Dollars in millions)

Year	Current dollars			Constant 1972 dollars[1]		
	Basic research	Applied research	Develop-ment	Basic research	Applied research	Develop-ment
1960	$ 1,197	$ 3,020	$ 9,306	$1,729	$4,380	$13,526
1961	1,401	3,065	9,850	2,004	4,399	14,181
1962	1,724	3,665	10,005	2,427	5,175	14,148
1963	1,965	3,742	11,352	2,720	5,201	15,812
1964	2,289	4,128	12,437	3,129	5,658	17,070
1965	2,555	4,339	13,150	3,416	5,818	17,662
1966	2,814	4,601	14,431	3,660	5,989	18,793
1967	3,056	4,780	15,310	3,853	6,036	19,352
1968	3,296	5,131	16,178	4,001	6,223	19,609
1969	3,441	5,316	16,874	3,985	6,139	19,462
1970	3,549	5,720	16,865	3,895	6,265	18,453
1971	3,672	5,739	17,265	3,836	5,985	17,993
1972	3,829	5,984	18,664	3,829	5,984	18,664
1973	3,946	6,597	20,175	3,766	6,266	19,115
1974	4,239	7,228	21,397	3,757	6,341	18,665
1975	4,608	7,863	22,742	3,720	6,297	18,136
1976	4,976	9,045	24,995	3,769	6,844	18,895
1977	5,534	9,746	27,549	3,937	6,945	19,657
1978	6,388	10,844	30,952	4,248	7,211	20,580
1979	7,252	12,370	35,350	4,436	7,570	21,631
1980	8,071	14,056	40,607	4,533	7,881	22,745
1981 (prelim.)	9,188	16,866	46,064	4,704	8,631	23,565
1982 (est.)	9,700	18,230	51,070	4,653	8,776	24,619
1983 (est.)	10,450	19,725	56,325	4,771	9,027	25,807

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: The National Science Foundation utilizes the following definitions of character of work in its resource surveys.

Basic research. Basic research has as its objective "a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." To take into account industrial goals, NSF modifies this definition for the industry sector to indicate that basic research advances scientific knowledge "not having specific commercial objectives, although such investigations may be in fields of present or potential interest to the reporting company."

Applied research. Applied research is directed toward gaining "knowledge or understanding necessary for determining the means by which a recognized and specific need may be met." In industry, applied research includes investigations directed "to the discovery of new scientific knowledge having specific commercial objectives with respect to products or processes."

Development. Development is the "systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes."

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figure 2-9.

Science Indicators—1982

Appendix table 2-6. Total research expenditures by source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities and colleges[1]	Nonprofit institutions
			Current dollars		
1960	$ 4,217	$ 2,403	$ 1,568	$ 138	$108
1961	4,466	2,628	1,556	154	128
1962	5,389	3,198	1,864	172	155
1963	5,707	3,436	1,908	193	170
1964	6,417	3,995	2,026	221	175
1965	6,894	4,333	2,115	252	194
1966	7,415	4,560	2,351	286	218
1967	7,836	4,895	2,381	325	235
1968	8,427	5,146	2,660	373	248
1969	8,757	5,226	2,860	403	268
1970	9,269	5,569	2,955	448	297
1971	9,411	5,537	3,041	515	318
1972	9,813	5,737	3,178	555	343
1973	10,543	6,103	3,496	580	364
1974	11,467	6,446	3,983	635	403
1975	12,471	7,079	4,222	702	468
1976	14,021	7,970	4,772	756	523
1977	15,280	8,609	5,260	829	582
1978	17,232	9,672	5,945	957	658
1979	19,622	10,913	6,885	1,109	715
1980	22,127	12,195	7,910	1,224	798
1981 (prelim.)	26,054	13,685	10,131	1,411	827
1982 (est.)	27,930	14,400	11,315	1,435	780
1983 (est.)	30,175	15,310	12,520	1,505	840
			Constant 1972 dollars[2]		
1960	$ 6,109	$3,472	$2,282	$198	$157
1961	6,403	3,757	2,244	219	183
1962	7,602	4,503	2,640	241	218
1963	7,921	4,758	2,661	266	236
1964	8,787	5,462	2,784	301	240
1965	9,234	5,794	2,844	336	260
1966	9,649	5,930	3,063	372	284
1967	9,889	6,172	3,012	409	296
1968	10,224	6,248	3,223	453	300
1969	10,124	6,050	3,297	468	309
1970	10,160	6,110	3,232	492	326
1971	9,821	5,785	3,167	538	331
1972	9,813	5,737	3,178	555	343
1973	10,032	5,823	3,307	556	346
1974	10,098	5,713	3,463	567	355
1975	10,017	5,713	3,359	570	375
1976	10,613	6,038	3,606	573	396
1977	10,882	6,123	3,756	589	414
1978	11,459	6,433	3,953	636	437
1979	12,006	6,677	4,213	679	437
1980	12,414	6,851	4,428	688	447
1981 (prelim.)	13,335	7,007	5,182	722	424
1982 (est.)	13,429	6,908	5,459	687	375
1983 (est.)	13,798	6,989	5,739	686	384

[1] Includes State and local government sources.
[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319), and unpublished data.

See figure 2-10.

Appendix table 2-7. Basic research expenditures by source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities and colleges[1]	Other nonprofit institutions
	Current dollars				
1960	$ 1,197	$ 715	$ 342	$ 72	$ 68
1961	1,401	874	361	85	81
1962	1,724	1,131	394	102	97
1963	1,965	1,311	425	121	108
1964	2,289	1,598	433	144	114
1965	2,555	1,809	461	164	121
1966	2,814	1,978	510	197	129
1967	3,056	2,201	492	223	140
1968	3,296	2,336	535	276	149
1969	3,441	2,441	540	298	162
1970	3,549	2,489	528	350	182
1971	3,672	2,529	547	400	196
1972	3,829	2,633	563	415	218
1973	3,946	2,709	605	408	224
1974	4,239	2,912	651	432	244
1975	4,608	3,139	705	478	286
1976	4,976	3,436	769	474	297
1977	5,534	3,821	850	526	337
1978	6,388	4,443	964	603	378
1979	7,252	5,043	1,091	707	411
1980	8,071	5,546	1,265	800	460
1981 (prelim.)	9,188	6,220	1,597	905	466
1982 (est.)	9,700	6,560	1,785	915	440
1983 (est.)	10,450	7,020	1,995	965	470
	Constant 1972 dollars[2]				
1960	$ 1,729	$1,030	$ 497	$103	$ 99
1961	2,004	1,246	521	121	116
1962	2,427	1,590	558	143	136
1963	2,720	1,811	592	167	150
1964	3,129	2,182	595	196	156
1965	3,416	2,415	620	219	162
1966	3,660	2,571	665	256	168
1967	3,853	2,774	622	281	176
1968	4,001	2,837	649	335	180
1969	3,985	2,829	623	346	187
1970	3,895	2,733	578	384	200
1971	3,836	2,644	570	418	204
1972	3,829	2,633	563	415	218
1973	3,766	2,589	573	391	213
1974	3,757	2,589	567	386	215
1975	3,720	2,540	562	388	230
1976	3,769	2,604	581	359	225
1977	3,937	2,716	607	374	240
1978	4,248	2,955	641	401	251
1979	4,436	3,085	667	433	251
1980	4,533	3,117	708	450	258
1981 (prelim.)	4,704	3,185	817	463	239
1982 (est.)	4,653	3,143	861	438	211
1983 (est.)	4,771	3,202	914	440	215

[1] Includes State and local government sources.
[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: For a definnition of basic research, see appendix table 2-5.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figure 2-11.

Appendix table 2-8. Applied research expenditures by source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities and colleges[1]	Other nonprofit institutions
			Current dollars		
1960	$ 3,020	$1,688	$ 1,226	$ 66	$ 40
1961	3,065	1,754	1,195	69	47
1962	3,665	2,067	1,470	70	58
1963	3,742	2,125	1,483	72	62
1964	4,128	2,397	1,593	77	61
1965	4,339	2,524	1,654	88	73
1966	4,601	2,582	1,841	89	89
1967	4,780	2,694	1,889	102	95
1968	5,131	2,810	2,125	97	99
1969	5,316	2,785	2,320	105	106
1970	5,720	3,080	2,427	98	115
1971	5,739	3,008	2,494	115	122
1972	5,984	3,104	2,615	140	125
1973	6,597	3,394	2,891	172	140
1974	7,228	3,534	3,332	203	159
1975	7,863	3,940	3,517	224	182
1976	9,045	4,534	4,003	282	226
1977	9,746	4,788	4,410	303	245
1978	10,844	5,229	4,981	354	280
1979	12,370	5,870	5,794	402	304
1980	14,056	6,649	6,645	424	338
1981 (prelim.)	16,866	7,465	8,534	506	361
1982 (est.)	18,230	7,840	9,530	520	340
1983 (est.)	19,725	8,290	10,525	540	370
			Constant 1972 dollars[2]		
1960	$ 4,380	$2,442	$ 1,785	$ 95	$ 58
1961	4,399	2,511	1,723	98	67
1962	5,175	2,913	2,082	98	82
1963	5,201	2,947	2,069	99	86
1964	5,658	3,280	2,189	105	84
1965	5,818	3,379	2,224	117	98
1966	5,989	3,359	2,398	116	116
1967	6,036	3,398	2,390	128	120
1968	6,223	3,411	2,574	118	120
1969	6,139	3,221	2,674	122	122
1970	6,265	3,377	2,654	108	126
1971	5,985	3,141	2,597	120	127
1972	5,984	3,104	2,615	140	125
1973	6,266	3,234	2,734	165	133
1974	6,341	3,124	2,896	181	140
1975	6,297	3,173	2,797	182	145
1976	6,844	3,434	3,025	214	171
1977	6,945	3,407	3,149	215	174
1978	7,211	3,478	3,312	235	186
1979	7,570	3,592	3,546	246	186
1980	7,881	3,734	3,720	238	189
1981 (prelim.)	8,631	3,822	4,365	259	185
1982 (est.)	8,776	3,765	4,598	249	164
1983 (est.)	9,027	3,787	4,825	246	169

[1] Includes State and local government sources.
[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: For a definition of applied research, see appendix table 2-5.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figure 2-11.

Appendix table 2-9. Development expenditures by source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities and colleges[1]	Other nonprofit institutions
			Current dollars		
1960	$ 9,306	$ 6,335	$ 2,948	$ 11	$ 12
1961	9,850	6,622	3,201	11	16
1962	10,005	6,713	3,259	13	20
1963	11,352	7,768	3,548	14	22
1964	12,437	8,542	3,861	14	20
1965	13,150	8,679	4,433	15	23
1966	14,431	9,408	4,977	18	28
1967	15,310	9,500	5,761	20	29
1968	16,178	9,782	6,345	17	34
1969	16,874	9,669	7,150	17	38
1970	16,865	9,323	7,489	13	40
1971	17,265	9,427	7,781	14	43
1972	18,664	10,071	8,532	19	42
1973	20,175	10,296	9,797	33	49
1974	21,397	10,404	10,895	42	56
1975	22,742	11,030	11,598	47	67
1976	24,995	11,944	12,922	52	77
1977	27,549	13,033	14,369	58	89
1978	30,952	14,261	16,505	78	108
1979	35,350	15,947	19,196	85	122
1980	40,607	17,521	22,861	90	135
1981 (prelim.)	46,064	20,067	25,766	101	130
1982 (est.)	51,070	22,210	28,640	105	115
1983 (est.)	56,325	24,315	31,765	110	135
			Constant 1972 dollars[2]		
1960	$13,526	$ 9,201	$ 4,291	$ 16	$ 18
1961	14,181	9,525	4,617	16	23
1962	14,148	9,486	4,616	18	28
1963	15,812	10,812	4,950	19	31
1964	17,070	11,717	5,306	19	28
1965	17,662	11,649	5,962	20	31
1966	18,793	12,250	6,484	23	36
1967	19,352	12,004	7,287	25	36
1968	19,609	11,860	7,687	21	41
1969	19,462	11,159	8,239	20	44
1970	18,453	10,206	8,189	14	44
1971	17,993	9,830	8,104	15	44
1972	18,664	10,071	8,532	19	42
1973	19,115	9,771	9,265	32	47
1974	18,665	9,113	9,467	37	48
1975	18,136	8,824	9,220	38	54
1976	18,895	9,034	9,764	39	58
1977	19,657	9,293	10,260	41	63
1978	20,580	9,483	10,973	52	72
1979	21,631	9,758	11,746	52	75
1980	22,745	9,821	12,797	51	76
1981 (prelim.)	23,565	10,267	13,179	52	67
1982 (est.)	24,619	10,693	13,821	50	55
1983 (est.)	25,807	11,130	14,566	50	61

[1] Includes State and local government sources.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: For a definition of development, see appendix table 2-5.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and unpublished data.

See figure 2-11.

Appendix table 2-10. Federal outlays for R&D and R&D plant, as a percent of total Federal outlays, and as a percent of the relatively controllable portion of the Federal outlays: 1960-83

(Dollars in billions)

Year	Total Federal outlays	Total Federal R&D and R&D plant outlays[1]	Outlays for R&D & R&D plant as a percent of total Federal outlays	Outlays for R&D & R&D plant as a percent of controllable Federal outlays
1960	$ 92.2	$ 7.7	8.4	NA
1961	97.8	9.3	9.5	NA
1962	106.8	10.4	9.7	NA
1963	111.3	12.0	10.8	NA
1964	118.6	14.7	12.4	NA
1965	118.4	14.9	12.6	NA
1966	134.7	16.0	11.9	NA
1967	157.6	16.9	10.7	16.3
1968	178.1	17.0	9.6	14.7
1969	183.6	16.3	8.9	14.6
1970	195.7	15.7	8.0	13.7
1971	210.2	16.0	7.6	14.0
1972	230.7	16.7	7.2	13.9
1973	245.6	17.5	7.1	14.4
1974	267.9	18.3	6.8	14.3
1975	324.2	19.6	6.0	12.8
1976	364.5	21.0	5.8	12.7
1977	400.5	23.4	5.8	13.0
1978	448.4	25.7	5.7	12.5
1979	491.0	27.8	5.7	12.3
1980	576.7	31.9	5.5	12.2
1981	657.2	35.8	5.5	12.5
1982 (est.)	728.4	39.3	5.4	12.7
1983 (est.)	805.2	42.4	5.3	12.6

[1] Reported by Federal agencies.

NA = not available.

SOURCE: Executive Office of the President, Council of Economic Advisers, *Economic Report of the President*, 1983, p. 248; Office of Management and Budget, *Budget of the U.S. Government, FY 1984*, 1983, pp. 9-38 and 9-39; National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1981, 1982 and 1983*, vol. XXXI (NSF 82-326), and earlier volumes.

See figure 2-12.

Science Indicators—1982

Appendix 2-11. Federal funds for R&D by major budget function: 1960-84

Year	Dollars in billions			As percent of total obligations	
	Total	Defense	All other	Defense	All other
1960	$ 8	$ 6	2	80	20
1961	9	7	2	77	23
1962	10	7	3	70	30
1963	13	8	5	62	38
1964	14	8	6	55	45
1965	15	7	7	50	50
1966	15	8	8	49	51
1967	17	9	8	52	48
1968	16	8	8	52	48
1969	16	8	7	54	46
1970	15	8	7	52	48
1971	16	8	7	52	48
1972	17	9	8	54	46
1973	17	9	8	54	46
1974	17	9	8	52	48
1975	19	10	9	51	49
1976	21	10	10	50	50
1977	24	12	12	50	50
1978	26	13	13	50	50
1979	28	14	14	50	50
1980	30	15	15	50	50
1981	33	18	15	55	45
1982	36	22	14	61	39
1983 (est.)	38	25	14	66	34
1984 (est.)	46	32	14	70	30

NOTE: Detail may not add to totals due to rounding. Estimates given for 1984 may change significantly as the result of congressional action on agency budget requests. Data for 1960-77 are shown in obligations; data for 1978-83 are shown in budget authority.

SOURCE: Executive Office of the President, Office of Management and Budget, "Special Analysis K," *Budget of the U.S. Government, 1984,* 1983.

See figure 2-14.

Science Indicators—1982

Appendix table 2-12. Federal funds[1] for R&D by budget functions: 1971-84

(Dollars in millions)

Function	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983 (est.)	1984 (est.)
Total	$15,542.5	$16,495.9	$16,800.2	$17,410.1	$19,038.8	$20,779.7	$23,542.2	$25,998.9	$28,080.4	$30,016.8	$33,319.3	$35,987.7	$38,386.3	$45,577.0
National defense	8,109.9	8,901.6	9,001.9	9,015.8	9,679.3	10,429.7	11,863.8	12,899.4	13,791.0	14,946.4	18,413.0	22,070.0	24,913.3	31,984.1
Health	1,287.8	1,546.7	1,585.0	2,068.6	2,170.2	2,350.6	2,628.5	2,967.7	3,401.3	3,694.3	3,870.8	3,867.5	4,247.7	4,356.0
Energy	555.8	574.0	629.7	759.2	1,363.4	1,648.5	2,561.8	3,134.4	3,461.4	3,603.2	3,501.4	2,920.2	2,533.2	2,217.3
Space research & technology	3,048.0	2,931.8	2,823.9	2,701.8	2,764.0	3,129.9	2,923.7	2,961.5	3,008.5	2,981.1	2,696.0	2,584.2	1,883.3	1,897.1
General science	512.5	625.3	657.6	749.4	813.3	857.7	973.8	1,050.2	1,119.1	1,232.6	1,340.0	1,353.3	1,489.6	1,718.0
Transportation	727.9	558.2	571.5	693.4	634.9	630.5	708.4	767.5	798.2	887.5	869.5	791.0	893.9	1,090.7
Natural resources & environment	415.5	478.5	553.8	516.0	624.3	683.0	753.1	903.9	1,009.6	999.3	1,060.5	942.8	913.2	796.9
Agriculture	259.0	294.4	308.1	313.1	341.8	382.5	456.7	501.3	551.6	585.3	658.5	692.7	746.6	748.3
Education, training, employment & social services	215.4	235.3	290.4	236.4	238.6	254.8	230.1	345.1	353.5	468.0	298.4	226.9	219.9	223.8
International affairs	31.9	28.6	28.3	23.8	29.0	42.4	66.3	57.2	116.8	127.3	160.0	165.0	152.1	160.8
Veterans benefits & services	62.9	69.1	74.3	84.8	94.8	97.7	107.0	111.1	122.8	125.8	142.9	139.2	157.6	159.4
Commerce & housing credit	89.5	49.7	50.2	50.8	64.9	68.7	70.5	76.7	92.7	102.1	105.5	103.9	106.9	91.1
Income security	144.9	106.3	106.3	70.9	71.9	48.3	55.2	67.3	56.8	77.2	42.6	31.6	42.0	43.4
Administration of justice	10.4	23.4	33.2	34.7	44.3	34.8	29.9	43.7	46.5	45.1	33.8	30.9	33.4	41.9
Community & regional development	64.6	65.8	78.4	82.1	92.5	108.5	100.9	91.9	127.3	119.4	104.3	62.5	47.7	39.2
General government	6.6	7.6	7.4	9.3	11.7	11.9	12.6	20.3	23.3	22.0	22.1	6.0	5.9	8.9

[1] Listed in descending order of 1984 budget authority. Data for the period 1971-77 are shown in obligations; data for 1978-84 are shown in budget authority.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Federal R&D Funding by Budget Function, Fiscal Years 1981-83*, 1982; Executive Office of the President, Office of Management and Budget, *Budget of the U.S. Government, 1984*, 1983; and unpublished data.

See figure 2-15.

Appendix table 2-13. Federal obligations for basic research by agency: 1967-83
(Dollars in millions)

Year	All agencies	USDA	DOD	HHS[1]	NASA	NSF	All other agencies
				Current dollars			
1967	$1,846	$100	$284	$ 490	$328	$239	$405
1968	1,841	100	264	517	321	252	386
1969	1,945	107	277	537	380	248	396
1970	1,926	116	317	513	358	245	377
1971	1,980	118	322	575	327	273	365
1972	2,187	137	329	665	332	368	356
1973	2,232	143	307	667	350	392	363
1974	2,388	146	303	850	306	415	368
1975	2,588	154	300	903	309	486	436
1976	2,768	171	327	986	293	524	467
1977	3,259	205	373	1,120	414	625	522
1978	3,699	243	410	1,292	480	678	596
1979	4,193	256	472	1,576	513	733	643
1980	4,674	276	540	1,763	559	815	721
1981	5,041	314	604	1,900	531	897	795
1982 (est.)	5,311	332	674	1,971	575	911	848
1983 (est.)	5,765	359	782	2,042	677	976	929
				Constant 1972 dollars[2]			
1967	$2,234	$126	$358	$ 617	$413	$301	$510
1968	2,237	122	321	628	390	306	469
1969	2,257	124	322	623	441	288	460
1970	2,116	127	348	563	393	269	414
1971	2,071	123	337	601	342	286	382
1972	2,187	137	329	665	332	368	356
1973	2,137	137	294	639	335	375	348
1974	2,131	130	270	759	273	370	328
1975	2,100	125	243	733	251	394	354
1976	2,099	130	248	748	222	397	354
1977	2,315	146	265	796	294	444	371
1978	2,460	162	273	859	319	451	397
1979	2,565	157	289	964	314	448	393
1980	2,628	155	304	992	314	458	406
1981	2,581	161	309	973	272	459	407
1982 (est.)	2,541	159	323	943	275	436	406
1983 (est.)	2,627	164	356	931	309	445	423

[1] Data for 1967-78 represent obligations by the Department of Health, Education and Welfare; 1979-83 data represent obligations by the Department of Health and Human Services.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Details may not add to totals because of rounding.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Fiscal Years, 1981, 1982, and 1983,* vol. XXXI (NSF 82-326), and detailed historical tables, 1982.

Science Indicators—1982

Appendix table 2-14. Federal obligations for basic research by field of science: 1967-83
(Dollars in millions)

Field[1]	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982 (est.)	1983 (est.)
All fields	$1,846	$1,841	$1,945	$1,926	$1,980	$2,187	$2,232	$2,388	$2,588	$2,768	$3,259	$3,698	$4,192	$4,674	$5,041	$5,311	$5,765
Life sciences	706	716	717	697	748	868	888	1,032	1,116	1,222	1,383	1,588	1,892	2,054	2,224	2,330	2,428
Biological & agricultural	419	496	504	485	519	597	609	692	747	818	934	1,079	1,279	1,339	1,462	1,533	1,601
Medical	233	206	197	199	211	246	253	318	342	374	415	468	560	657	706	740	769
Other life sciences	53	13	15	13	17	25	27	23	27	29	35	42	52	58	55	57	59
Environmental sciences[1]	209	199	235	243	261	263	273	292	281	294	388	451	457	522	533	524	559
Physical sciences	596	589	651	601	593	637	628	650	709	721	890	941	1,050	1,221	1,325	1,432	1,650
Chemistry	118	113	119	127	110	141	146	149	159	168	209	203	225	257	298	323	349
Physics	349	353	351	339	351	362	351	360	379	388	467	519	536	668	735	778	905
Astronomy	107	110	174	131	124	129	122	133	163	160	193	210	281	279	274	314	379
Other physical sciences	22	13	7	5	8	6	10	7	8	5	21	10	9	16	17	18	17
Psychology	53	47	47	48	46	51	45	46	59	46	56	84	75	84	91	92	100
Mathematics and computer sciences	64	66	54	59	55	67	60	53	62	82	83	98	104	116	140	165	186
Engineering	153	153	152	202	191	206	221	215	263	273	338	376	435	465	526	588	655
Social sciences	55	60	72	64	70	80	80	75	74	86	96	124	130	147	137	122	124
Other sciences	10	11	18	11	16	16	36	26	26	43	26	35	50	64	65	59	62

[1] Includes atmospheric sciences, geological sciences, oceanography and other environmental sciences.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Fiscal Years 1981, 1982, and 1983* vol. XXXI (NSF 82-326), and detailed historical tables, 1982.

See figure 2-18 and table 2-1 in the text.

Appendix table 2-15. Federal outlays for R&D plant: 1960-83

(Dollars in millions)

Year	Current dollars	Constant 1972 dollars[1]
1960	$ 443.8	$ 637.9
1961	539.1	766.2
1962	555.2	777.9
1963	673.6	928.3
1964	948.1	1,292.0
1965	1,077.4	1,436.9
1966	1,047.8	1,361.5
1967	792.7	997.9
1968	723.8	879.4
1969	657.0	762.5
1970	578.9	635.9
1971	612.7	640.8
1972	564.4	564.4
1973	638.4	611.2
1974	704.6	628.8
1975	829.7	673.1
1976	800.6	607.1
1977	800.2	568.5
1978	1,107.8	736.9
1979	1,202.8	735.8
1980	1,481.7	833.3
1981	1,606.7	822.8
1982 (est.)	1,695.3	811.1
1983 (est.)	1,207.9	550.4

[1] GNP fiscal year implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Research and Development Detailed Historical Tables: Fiscal Years 1967-1983,* 1982, and earlier years.

See figure 2-20.

Science Indicators—1982

Appendix table 2-16. Federal obligations for R&D plant by performer: 1962-83

(Dollars in millions)

Year	Total	Federal intramural laboratories	Industry[1]	Universities and colleges	FFRDC's[2]	Nonprofit institutions[1]
			Current dollars			
1962	$ 555.2	NA	NA	NA	NA	NA
1963	1,168.3	NA	NA	NA	NA	NA
1964	1,098.5	NA	NA	NA	NA	NA
1965	1,131.6	$ 913.0	NA	$141.6	$ 50.2	NA
1966	858.3	629.0	NA	162.9	31.1	NA
1967	620.1	239.0	NA	111.7	138.8	NA
1968	603.8	294.2	$ 81.7	98.1	101.7	$ 20.9
1969	669.0	260.4	141.7	61.9	176.6	25.8
1970	524.4	166.0	102.3	56.1	169.0	28.8
1971	611.2	200.0	167.4	49.2	178.7	5.8
1972	602.1	246.6	142.4	45.3	130.4	30.0
1973	774.3	323.8	221.8	42.6	162.3	18.8
1974	766.3	308.7	294.1	25.0	118.4	8.3
1975	820.7	346.8	291.9	35.9	131.8	14.1
1976	836.7	316.8	279.6	35.2	189.6	15.6
1977	1,367.2	711.9	319.3	37.0	277.8	12.8
1978	1,295.7	518.0	334.0	54.6	376.3	12.7
1979	1,475.5	544.8	438.8	42.0	414.1	27.0
1980	1,555.7	491.1	560.0	41.8	426.3	33.2
1981	1,485.7	468.0	548.7	37.1	370.9	61.2
1982 (est.)	1,483.9	460.3	483.5	32.9	433.2	73.9
1983 (est.)	1,298.6	559.2	262.6	45.9	274.5	156.4
			Constant 1972 dollars[3]			
1962	$ 777.9	NA	NA	NA	NA	NA
1963	1,610.1	NA	NA	NA	NA	NA
1964	1,497.0	NA	NA	NA	NA	NA
1965	1,509.2	$1,217.7	NA	$188.9	$ 67.0	NA
1966	1,115.3	817.3	NA	211.7	40.4	NA
1967	780.6	300.9	NA	140.6	174.7	NA
1968	733.6	357.4	$ 99.3	119.2	123.6	$ 25.4
1969	776.4	302.2	164.4	71.8	204.9	29.9
1970	576.0	182.3	112.4	61.6	185.6	31.6
1971	639.2	209.2	175.1	51.5	186.9	6.1
1972	602.1	246.6	142.4	45.3	130.4	30.0
1973	741.5	310.1	212.4	40.8	155.4	18.0
1974	684.6	275.8	262.7	22.3	105.8	7.4
1975	666.9	281.8	237.2	29.2	107.1	11.5
1976	635.5	240.6	212.4	26.7	144.0	11.8
1977	972.7	506.5	227.2	26.3	197.7	9.1
1978	864.0	345.4	222.7	36.4	250.9	8.5
1979	906.1	334.6	269.5	25.8	254.3	16.6
1980	874.9	276.2	314.9	23.5	239.7	18.7
1981	760.8	239.7	281.0	19.0	189.9	31.3
1982 (est.)	709.9	220.2	231.3	15.7	207.3	35.4
1983 (est.)	591.8	254.8	119.7	20.9	125.1	71.3

[1] Expenditures for federally funded research and development centers administered by industry and by nonprofit institutions are included in the totals of the respective sectors.

[2] Federally funded research and development centers administered by universities.

[3] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NA = not available.

NOTE: Detail may not add to totals because of rounding. Totals do not include foreign performers.

SOURCE: National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years, 1981, 1982, and 1983,* vol. XXXI (NSF 82-326) and earlier years.

See figure 2-22.

Appendix table 3-1. Scientists and engineers by field, sex and labor force status: 1976–81

Field and sex	Total				Labor force				Outside labor force			
	1976	1978	1980	1981	1976	1978	1980	1981	1976	1978	1980	1981
All S/E fields	2,523,600	2,873,500	3,149,500	3,381,100	2,369,000	2,671,000	2,941,200	3,167,400	154,600	202,600	208,300	213,700
Men	2,270,600	2,556,400	2,739,500	2,913,200	2,148,500	2,391,600	2,591,700	2,741,900	122,100	164,800	167,800	171,300
Women	753,000	317,100	410,000	467,900	220,500	279,300	369,500	425,500	32,500	37,800	40,400	42,500
Physical scientists	223,600	255,100	264,800	271,800	200,700	221,400	226,900	233,200	22,900	33,700	37,900	38,600
Men	196,300	223,100	228,600	234,500	178,500	196,600	199,100	204,500	17,800	26,500	29,500	29,900
Women	27,300	32,000	36,200	37,400	22,200	24,800	27,800	28,700	5,100	7,200	8,300	8,700
Mathematical scientists	96,000	106,000	127,300	141,600	90,200	99,300	120,000	134,000	5,800	6,800	7,300	7,600
Men	79,700	87,800	101,500	110,300	76,200	83,000	96,500	105,300	3,500	4,700	4,900	5,000
Women	16,300	18,300	25,800	31,300	14,000	16,200	23,500	28,700	2,300	2,000	2,300	2,600
Computer specialists	209,500	306,800	357,400	430,400	204,100	299,600	349,900	422,500	5,400	7,100	7,500	7,900
Men	171,900	239,400	262,200	314,600	169,900	236,700	259,500	311,600	2,100	2,700	2,800	3,000
Women	37,600	67,400	95,200	115,800	34,200	62,900	90,400	110,900	3,400	4,500	4,800	4,900
Environmental scientists[1]	70,800	89,700	103,700	116,100	66,300	82,900	95,400	106,500	4,600	6,700	8,300	9,600
Men	65,600	81,000	91,200	99,500	61,900	75,200	84,300	91,800	3,700	5,700	6,900	7,700
Women	5,300	8,700	12,500	16,500	4,300	7,700	11,000	14,700	900	1,000	1,500	1,900
Life scientists	298,300	349,400	407,200	439,800	282,900	326,900	383,600	415,100	15,400	22,500	23,600	24,600
Men	242,700	280,700	316,500	335,400	234,600	268,600	303,400	322,000	8,100	12,100	13,100	13,400
Women	55,600	68,700	90,700	104,400	48,300	58,400	80,200	93,100	7,300	10,300	10,500	11,300
Social scientists	240,500	223,700	231,300	246,600	221,300	206,300	214,700	229,600	19,100	17,400	16,700	17,000
Men	182,600	168,500	169,700	179,400	172,000	157,900	159,500	169,100	10,700	10,700	10,100	10,300
Women	57,800	55,100	61,700	67,100	49,400	48,400	55,100	60,500	8,500	6,700	6,600	6,700
Psychologists	118,200	127,400	134,000	141,700	112,300	119,600	126,000	133,200	5,900	7,800	8,000	8,500
Men	77,900	81,300	81,000	82,800	75,800	78,600	77,900	79,500	2,100	2,700	3,100	3,200
Women	40,300	46,100	53,100	59,000	36,600	41,000	48,100	53,700	3,800	5,000	4,900	5,300
Engineers	1,266,700	1,415,500	1,523,700	1,593,100	1,191,300	1,314,900	1,424,800	1,493,200	75,400	100,600	99,000	99,900
Men	1,253,800	1,394,700	1,488,900	1,556,600	1,179,700	1,295,000	1,391,400	1,458,000	74,100	99,600	97,400	98,600
Women	12,900	20,800	34,900	36,500	11,600	19,900	33,300	35,200	1,300	1,000	1,500	1,300

[1]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314) and unpublished data.

Science Indicators—1982

Appendix table 3-2. Scientists and engineers in the labor force by field, sex and employment status: 1976–81

Field and sex	Total employed				Employed in S/E jobs				Employed but not in S/E jobs				Unemployed but seeking employment			
	1976	1978	1980	1981	1976	1978	1980	1981	1976	1978	1980	1981	1976	1978	1980	1981
All S/E fields	2,324,500	2,643,300	2,910,500	3,134,100	2,103,500	2,397,500	2,593,600	2,795,600	221,000	245,800	316,900	338,500	44,500	27,600	30,700	33,300
Men	2,110,700	2,368,500	2,546,400	2,715,000	1,913,700	2,153,100	2,277,400	2,429,500	197,000	215,400	269,000	285,500	37,900	23,100	25,300	27,000
Women	213,900	274,800	364,100	419,100	189,800	244,400	316,200	366,000	24,100	30,400	47,900	53,100	6,600	4,500	5,400	6,300
Physical scientists	196,000	217,600	223,200	229,500	168,700	188,800	186,900	191,400	27,300	28,800	36,300	38,100	4,700	3,800	3,700	3,700
Men	174,500	193,600	196,100	201,600	152,000	170,300	165,200	169,000	22,500	23,300	30,900	32,600	4,000	3,000	3,000	2,900
Women	21,500	24,000	27,100	28,000	16,700	18,500	21,700	22,400	4,800	5,500	5,400	5,600	700	800	800	700
Mathematical scientists	87,800	98,500	119,000	132,900	78,000	88,600	106,800	118,700	9,800	9,900	12,200	14,200	2,400	800	1,000	1,100
Men	74,300	82,600	96,000	104,800	66,100	75,000	87,100	94,900	8,200	7,600	8,900	9,900	1,900	400	600	500
Women	13,500	15,800	23,000	28,100	11,900	13,700	19,700	23,800	1,600	2,100	3,300	4,300	400	400	500	600
Computer specialists	201,500	298,000	348,000	420,200	193,300	285,900	327,600	397,000	8,200	12,100	20,400	23,200	2,600	1,600	1,900	2,400
Men	168,300	235,300	257,800	309,600	161,000	224,200	252,000	302,100	7,300	11,100	5,800	7,500	1,600	1,400	1,700	2,000
Women	33,200	62,700	90,200	110,500	32,300	61,700	75,600	94,900	900	1,000	14,600	15,600	1,000	200	200	400
Environmental scientists[1]	64,700	81,000	93,000	103,900	57,000	69,800	78,800	87,800	7,700	11,200	14,200	16,100	1,500	1,900	2,400	2,600
Men	60,500	73,400	82,300	89,600	53,800	64,000	69,800	76,000	6,700	9,400	12,500	13,600	1,400	1,800	2,100	2,200
Women	4,200	7,600	10,700	14,300	3,100	5,800	9,000	11,800	1,100	1,800	1,700	2,500	100	100	300	400
Life scientists	279,000	323,100	379,600	411,000	257,700	300,800	351,400	381,400	21,300	22,300	28,200	29,600	4,000	3,800	4,100	4,100
Men	232,500	265,600	300,300	318,900	213,900	247,100	277,600	295,100	18,600	18,500	22,700	23,800	2,200	3,000	3,100	3,200
Women	46,500	57,500	79,200	92,100	43,800	53,800	73,800	86,300	2,700	3,700	5,400	5,800	1,800	800	1,000	1,000
Social scientists	217,600	203,300	211,400	226,000	172,400	159,500	171,900	183,900	45,200	43,800	39,500	42,100	3,700	3,000	3,300	3,600
Men	169,500	156,100	157,400	166,800	132,800	122,400	127,100	134,700	36,700	33,700	30,300	32,100	2,500	1,800	2,100	2,300
Women	48,100	47,300	54,000	59,200	39,500	37,000	44,800	49,100	8,600	10,300	9,200	10,100	1,200	1,100	1,100	1,300
Psychologists	109,500	118,100	124,400	131,200	99,900	104,800	109,700	115,300	9,600	13,300	14,700	15,900	2,800	1,500	1,700	2,000
Men	74,200	77,600	77,100	78,700	68,200	69,100	68,400	69,300	6,000	8,500	8,700	9,400	1,600	900	800	800
Women	35,400	40,400	47,300	52,500	31,700	35,700	41,300	46,000	3,700	4,700	6,000	6,500	1,200	600	900	1,200
Engineers	1,168,400	1,303,700	1,412,100	1,479,400	1,076,600	1,199,300	1,260,400	1,320,100	91,800	104,400	151,700	159,300	22,900	11,100	12,700	13,800
Men	1,157,000	1,284,300	1,379,400	1,445,000	1,065,800	1,181,000	1,230,200	1,288,400	91,200	103,300	149,200	156,600	22,700	10,700	12,000	13,000
Women	11,400	19,400	32,700	34,500	10,800	18,300	30,200	31,700	600	1,100	2,500	2,800	200	400	700	800

[1]Includes earth scientists, oceanographers and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314) and unpublished data.

See figures 3-4 and 3-11.

Appendix table 3-3. Scientists and engineers by field and employment status: 1981

Field	Total	In the labor force: Labor force total	Total employed: Total employed	Total employed: Employed in S/E	Total employed: Employed outside S/E	Unemployed but seeking employment	Outside the labor force
All S/E fields	3,381,100	3,167,400	3,134,100	2,795,600	338,500	33,300	213,700
Physical scientists	271,800	233,200	229,500	191,400	38,100	3,700	38,600
Chemists	178,300	150,000	147,600	120,700	26,900	2,400	28,300
Physicists & astronomers	68,800	61,200	60,000	52,400	7,600	1,200	7,600
Other physical scientists	24,800	22,100	22,000	18,300	3,700	100	2,700
Mathematical scientists	141,600	134,000	132,900	118,700	14,200	1,100	7,600
Mathematicians	96,900	90,900	90,100	79,000	11,100	800	6,100
Statisticians	44,600	43,100	42,800	39,800	3,000	400	1,500
Computer specialists	430,400	422,500	420,200	397,000	23,200	2,400	7,900
Environmental scientists	116,100	106,500	103,900	87,800	16,100	2,600	9,600
Earth scientists	88,900	81,500	79,100	65,100	14,000	2,400	7,400
Oceanographers	3,000	2,800	2,800	2,600	200	([1])	300
Atmospheric scientists	24,100	22,200	22,100	20,100	2,000	200	1,900
Engineers	1,593,100	1,493,200	1,479,400	1,320,100	159,300	13,800	99,900
Aeronautical & astronautical	52,600	50,700	50,200	45,200	5,000	500	1,900
Chemical	84,400	80,300	79,400	72,700	6,700	900	4,100
Civil	213,700	202,500	200,300	185,600	14,700	2,200	11,300
Electrical & electronic	293,200	281,400	279,200	260,000	19,200	2,200	11,800
Mechanical	261,300	251,200	249,500	231,100	18,400	1,800	10,000
Other engineers	687,900	627,100	620,900	525,400	95,500	6,200	60,700
Life scientists	439,800	415,100	411,000	381,400	29,600	4,100	24,600
Biological scientists	221,500	207,000	204,900	186,900	18,000	2,100	14,500
Agricultural scientists	173,100	167,500	166,200	156,300	9,900	1,400	5,500
Medical scientists	45,200	40,600	39,900	38,300	1,600	700	4,600
Psychologists	141,700	133,200	131,200	115,300	15,900	2,000	8,500
Social scientists	246,600	229,600	226,000	183,900	42,100	3,600	17,000
Economists	88,800	83,200	82,000	70,000	12,000	1,200	5,600
Sociologists & anthropologists	65,200	60,700	60,000	49,300	16,700	700	4,400
Other social scientists	92,600	85,600	84,000	64,600	19,400	1,700	7,000

[1]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figures 3-1, 3-2 and 3-5.

Appendix table 3-4. Doctoral scientists and engineers by field, sex, and labor force status: 1973–81

Field and sex	Total population			In labor force			Total employed			Outside labor force		
	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981
All S/E fields	238,900	332,300	363,900	222,900	316,700	346,200	220,400	313,800	343,500	10,700	15,600	17,700
Men	218,000	294,400	318,100	205,300	282,400	304,300	203,500	280,400	302,600	8,300	12,000	13,900
Women	20,900	37,900	45,700	17,600	34,300	41,900	17,000	33,300	40,900	2,400	3,600	3,800
Physical scientists	53,000	64,300	67,700	49,400	60,900	63,700	48,500	60,200	63,200	2,700	3,400	4,000
Men	50,500	60,600	63,300	47,300	57,600	59,800	46,600	57,000	59,400	2,300	3,000	3,500
Women	2,500	3,700	4,400	2,000	3,200	4,200	1,900	3,100	3,800	400	400	500
Mathematical scientists	13,100	16,100	16,500	12,300	15,400	15,700	12,100	15,300	15,600	500	700	800
Men	12,100	14,800	15,000	11,500	14,200	14,400	11,400	14,200	14,300	400	600	600
Women	1,000	1,300	1,500	800	1,100	1,300	800	1,100	1,300	100	100	100
Computer specialists	2,700	6,800	9,100	2,700	6,800	9,100	2,700	6,700	9,000	(1)	(1)	(1)
Men	2,600	6,400	8,400	2,600	6,400	8,300	2,600	6,400	8,300	(1)	(1)	(1)
Women	100	400	700	100	400	700	100	400	700	(1)	(1)	(1)
Environmental scientists[2]	10,900	15,100	16,600	10,400	14,700	16,100	10,300	14,600	16,000	300	400	500
Men	10,600	14,400	15,700	10,200	14,000	15,200	10,100	14,000	15,200	300	400	400
Women	300	700	900	300	600	900	300	600	900	(1)	(1)	(1)
Life scientists	63,600	86,300	93,800	58,600	81,000	87,700	58,000	80,100	86,700	3,500	5,400	6,100
Men	55,800	73,200	78,600	52,200	69,400	74,000	51,900	68,900	73,500	2,500	3,800	4,600
Women	7,800	13,100	15,200	6,400	11,500	13,700	6,100	11,100	13,200	1,000	1,600	1,500
Social scientists	31,200	52,000	56,500	28,400	49,200	53,400	28,100	48,700	52,900	1,700	2,800	3,100
Men	27,700	43,800	47,000	25,400	41,700	44,700	25,200	41,400	44,500	1,400	2,200	2,300
Women	3,500	8,100	9,500	3,000	7,400	8,700	2,900	7,200	8,400	300	600	800
Psychologists	27,200	40,300	45,400	25,200	38,400	43,600	24,900	38,000	43,100	1,200	1,800	1,900
Men	21,500	30,100	32,600	20,200	29,200	31,500	20,100	28,800	31,200	700	1,100	1,100
Women	5,600	10,200	12,800	4,900	9,400	12,000	4,800	9,200	11,900	500	700	800
Engineers	37,300	51,600	58,300	36,100	50,600	57,000	35,800	50,300	57,000	700	1,100	1,300
Men	37,100	51,000	57,500	35,900	50,000	56,300	35,600	49,700	56,200	700	1,000	1,300
Women	200	600	800	100	500	800	100	500	800	(1)	(1)	(1)

[1]Less than 50.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977–81) and unpublished data.

See figure 3-11.

Science Indicators—1982

Appendix table 3-5. Doctoral scientists and engineers in the labor force by field, sex, and employment status: 1973–81

Field and sex	Employed in S/E jobs			Employed in non-S/E jobs			Postdoctorates			Unemployed but seeking employment		
	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981
All S/E fields	200,600	277,200	303,600	14,100	26,400	29,400	5,700	10,200	10,500	2,500	2,900	2,600
Men	185,900	249,400	269,700	12,700	23,000	25,100	4,800	8,000	7,800	1,800	2,000	1,700
Women	14,700	27,700	33,900	1,400	3,400	4,200	900	2,200	2,800	700	900	1,000
Physical scientists	42,400	52,200	54,700	4,200	5,800	6,000	1,900	2,200	2,500	900	700	500
Men	40,900	49,700	51,800	4,000	5,400	5,500	1,700	1,900	2,100	700	600	400
Women	1,500	2,500	3,000	300	400	400	100	300	300	100	100	100
Mathematical scientists	11,600	13,900	14,000	400	1,200	1,500	100	200	100	200	100	100
Men	10,900	12,900	12,800	400	1,100	1,400	100	200	100	200	([1])	100
Women	700	1,000	1,200	([1])	100	100	([1])	([1])	([1])	([1])	([1])	([1])
Computer specialists	2,700	6,600	9,000	([1])	100	100	([1])	([1])	([1])	([1])	([1])	([1])
Men	2,600	6,200	8,300	([1])	100	100	([1])	([1])	([1])	([1])	([1])	([1])
Women	100	400	700	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])
Environmental scientists[2]	9,900	13,800	15,100	300	500	700	200	300	200	100	100	100
Men	9,600	13,200	14,300	300	500	700	200	300	200	100	([1])	100
Women	200	600	800	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])
Life scientists	52,800	69,900	75,700	2,400	4,000	4,400	2,800	6,200	6,700	600	900	1,000
Men	47,700	60,900	65,300	2,000	3,300	3,500	2,200	4,700	4,700	300	500	600
Women	5,100	9,000	10,400	400	700	800	600	1,500	2,000	300	400	500
Social scientists	24,200	39,400	43,200	3,700	8,800	9,300	200	500	400	300	500	400
Men	21,700	33,700	36,600	3,300	7,300	7,800	200	300	200	200	300	100
Women	2,400	5,600	6,700	400	1,500	1,600	([1])	100	200	100	200	300
Psychologists	23,100	34,500	39,000	1,500	2,900	3,600	300	600	500	300	400	500
Men	18,700	26,300	28,500	1,200	2,100	2,400	200	400	300	100	300	300
Women	4,400	8,200	10,500	400	800	1,200	100	200	200	100	200	100
Engineers	33,900	46,900	52,900	1,600	3,100	3,800	200	300	200	300	300	([1])
Men	33,800	46,400	52,200	1,600	3,000	3,800	200	200	200	300	200	([1])
Women	100	500	700	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])

[1]Less than 50.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977–81) and unpublished data.

Science Indicators—1982

Appendix table 3-6. Doctoral scientists and engineers by field and employment status: 1981

Field	Total	In the labor force: Labor force total	Total employed	In S/E	Outside S/E	In post-doctoral appointments	Unemployed but seeking employment	Outside the labor force
All S/E fields	363,800	346,200	343,500	303,600	29,400	10,500	2,600	17,700
Physical scientists	67,700	63,700	63,200	54,700	6,000	2,500	500	4,000
Chemists	45,400	42,300	42,000	36,500	3,800	1,600	300	3,100
Physicists and astronomers	22,300	21,400	21,200	18,200	2,200	900	200	900
Mathematical scientists	16,500	15,700	15,600	14,000	1,500	100	100	800
Mathematicians	13,800	13,100	13,000	11,600	1,300	100	100	700
Statisticians	2,700	2,600	2,600	2,400	200	([1])	([1])	100
Computer specialists	9,100	9,100	9,000	9,000	100	([1])	([1])	([1])
Environmental scientists	16,600	16,100	16,000	15,100	700	200	100	500
Earth scientists	12,600	12,200	12,100	11,400	600	100	100	400
Oceanographers	1,800	1,800	1,800	1,700	([1])	([1])	([1])	([1])
Atmospheric scientists	2,200	2,100	2,100	2,000	100	100	([1])	([1])
Engineers	58,300	57,000	57,000	52,900	3,800	200	([1])	1,300
Aeronautical	2,500	2,500	2,500	2,200	300	100	([1])	([1])
Chemical	7,600	7,200	7,100	6,300	800	([1])	([1])	400
Civil	6,000	5,900	5,900	5,500	400	([1])	([1])	100
Electrical	10,800	10,700	10,700	10,100	600	([1])	([1])	200
Mechanical	5,600	5,400	5,400	5,000	400	([1])	([1])	200
Other engineers	25,700	25,400	25,300	23,900	1,300	100	([1])	300
Life scientists	93,800	87,700	86,700	75,700	4,400	6,700	1,000	6,100
Biological scientists	54,400	50,500	49,700	42,000	2,800	4,900	900	3,900
Agricultural scientists	17,300	15,900	15,900	14,600	1,100	100	100	1,300
Medical scientists	22,100	21,200	21,200	19,100	500	1,600	100	900
Psychologists	45,400	43,600	43,100	39,000	3,600	500	500	1,900
Social scientists	56,500	53,400	52,900	43,200	9,300	400	400	3,100
Economists	14,300	13,500	13,400	11,100	2,300	([1])	([1])	800
Sociologists and anthropologists	11,900	11,200	11,000	8,900	1,900	100	200	800
Other social scientists	30,300	28,700	28,500	23,200	5,100	200	200	1,500

[1] Less than 50.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981* (NSF 82-332).

See figure 3-2.

Science Indicators—1982

Appendix table 3-7. Average annual percent increases in employment in science and engineering and other economic variables: 1976-81

	1976-80	1980-81	1976-81
Scientists and engineers	5.4	7.8	5.9
Scientists	6.7	10.7	7.5
Engineers	4.0	4.7	4.2
Professional and technical workers	4.0	2.8	3.8
Nonfarm wage and salary workers	3.3	1.1	2.9
Gross national product	3.3	2.0	3.0

SOURCES: National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314) and unpublished data; U.S. Department of Labor, *Employment and Training Report of the President, 1982,* p. 177; and *Economic Report of the President, 1982,* pp. 243 and 275.

See figure 3-3.

Science Indicators—1982

Appendix table 3-8. Employed scientists and engineers by field, sex, and primary work activity: 1976–81

Field and sex	Total			Research			Development			Management of R&D		
	1976	1980	1981	1976	1980	1981	1976	1980	1981	1976	1980	1981
All fields	2,324,500	2,910,500	3,134,100	250,400	330,000	355,600	376,600	471,200	515,500	200,900	221,900	224,900
Men	2,110,900	2,546,400	2,715,000	209,000	268,000	285,500	361,900	443,900	482,500	192,000	211,400	213,300
Women	213,900	364,100	419,100	41,500	62,000	70,000	14,700	27,300	33,000	8,900	10,400	11,600
Physical scientists	196,000	223,200	229,500	57,200	67,200	67,600	20,800	27,700	28,300	21,600	22,200	21,900
Men	174,500	196,100	201,600	49,400	58,200	58,700	19,800	25,600	26,000	21,200	21,600	21,200
Women	21,500	27,100	28,000	7,900	9,000	8,800	1,100	2,200	2,300	500	700	700
Mathematical scientists	87,800	119,000	132,900	10,100	12,500	13,000	5,100	6,200	6,800	6,300	6,700	6,900
Men	74,300	96,000	104,800	9,300	10,900	11,200	3,900	5,300	5,800	5,700	6,300	6,400
Women	13,500	23,000	28,100	800	1,600	1,900	1,200	900	1,100	600	400	500
Computer specialists	201,500	348,000	420,200	4,400	10,300	12,000	40,300	47,600	57,800	10,500	14,500	16,000
Men	168,300	257,800	309,600	3,500	8,000	9,300	32,300	36,800	44,200	9,500	12,900	14,000
Women	33,200	90,200	110,500	800	2,400	2,700	7,900	10,800	13,600	1,000	1,600	2,000
Environmental scientists[1]	64,700	93,000	103,900	14,900	21,700	24,100	3,500	6,300	7,800	5,700	5,200	5,400
Men	60,500	82,300	89,600	12,900	19,000	20,500	3,400	5,800	6,800	5,600	4,700	4,800
Women	4,200	10,700	14,300	2,200	2,800	3,600	100	500	1,000	200	600	600
Engineers	1,168,400	1,412,100	1,479,400	51,000	64,700	70,500	296,100	364,300	394,500	109,400	127,400	127,800
Men	1,157,000	1,379,400	1,445,000	49,000	60,700	66,100	293,000	356,000	384,900	108,700	126,100	126,700
Women	11,400	32,700	34,500	2,100	4,000	4,400	3,100	8,300	9,700	700	1,200	1,100
Life scientists	279,000	379,600	411,000	76,600	113,700	124,900	8,200	13,300	14,300	23,100	21,900	22,300
Men	232,500	300,300	318,900	57,800	83,200	89,600	7,100	10,500	11,100	22,000	20,200	20,600
Women	46,500	79,200	92,100	18,800	30,500	35,400	1,100	2,800	3,200	1,100	1,600	1,700
Psychologists	109,500	124,400	131,200	10,300	12,500	13,700	700	1,800	1,700	6,600	8,000	8,400
Men	74,200	77,100	78,700	7,200	8,500	8,800	700	1,000	900	5,600	6,200	6,000
Women	35,400	47,300	52,500	3,100	4,000	5,000	([2])	800	800	1,000	1,800	2,400
Social scientists	217,600	211,400	226,000	25,900	27,200	29,700	1,800	4,100	4,300	17,600	15,900	16,300
Men	169,500	157,400	166,800	20,100	19,500	21,400	1,600	3,000	2,800	13,900	13,400	13,700
Women	48,100	54,000	59,200	5,800	7,700	8,100	200	1,100	1,500	3,700	2,500	2,600

(continued)

Appendix table 3-8. (Continued)

Field and sex	Management			Teaching			Production and inspection			Other activities[3]		
	1976	1980	1981	1976	1980	1981	1976	1980	1981	1976	1980	1981
All fields	405,600	438,900	449,400	229,800	268,200	288,900	275,000	396,000	430,200	586,300	784,300	869,500
Men	389,100	415,800	424,300	189,100	207,600	220,000	261,800	367,900	396,300	507,800	631,800	693,000
Women	16,500	23,100	25,100	40,700	60,600	69,000	13,300	28,100	34,000	78,400	152,500	176,400
Physical scientists	17,700	18,800	19,100	22,200	26,100	28,300	26,600	31,100	33,700	29,700	30,200	30,800
Men	16,100	17,400	17,700	20,000	22,300	23,800	23,300	26,400	28,500	24,800	24,700	25,600
Women	1,100	1,400	1,500	2,200	3,800	4,400	3,300	4,700	5,100	4,900	5,400	5,100
Mathematical scientists	10,400	11,200	11,500	31,500	40,200	44,100	4,200	3,800	4,400	20,200	38,300	46,100
Men	10,200	9,800	9,900	26,600	32,500	35,000	3,500	3,600	4,200	15,100	27,500	32,500
Women	200	1,400	1,700	4,900	7,700	9,100	700	200	200	5,000	10,700	13,500
Computer specialists	20,200	24,600	26,700	7,100	9,000	10,800	8,900	11,800	14,600	110,200	230,000	282,300
Men	18,900	21,900	23,800	5,500	7,100	8,700	7,100	9,700	11,600	91,300	161,400	198,000
Women	1,300	2,800	2,900	1,600	2,000	2,100	1,800	2,100	3,000	18,900	68,600	84,300
Environmental scientists[1]	9,300	10,700	11,300	6,800	9,100	10,200	6,500	13,800	16,300	18,100	26,000	28,700
Men	9,200	10,400	10,900	6,100	8,200	9,000	6,300	11,700	13,300	17,300	22,500	24,300
Women	([2])	300	400	700	800	1,200	200	2,100	2,900	900	3,600	4,400
Engineers	247,500	267,500	271,500	27,800	32,500	34,600	186,600	268,700	283,900	250,000	287,000	296,500
Men	246,700	265,500	269,600	27,700	32,000	33,900	184,500	261,300	275,900	247,500	277,400	287,900
Women	700	2,000	1,900	100	600	700	2,100	7,400	8,000	2,700	9,200	8,700
Life scientists	43,400	55,100	57,400	45,000	59,000	62,300	30,400	51,900	60,900	52,200	64,600	69,000
Men	41,100	50,700	52,200	34,900	44,600	46,200	27,000	43,200	49,300	42,500	47,800	49,900
Women	2,300	4,500	5,200	10,100	14,400	16,100	3,400	8,700	11,600	9,700	16,700	19,100
Psychologists	12,100	12,600	13,000	31,900	37,500	40,300	2,200	4,600	4,800	45,800	47,400	49,300
Men	9,400	9,200	9,300	21,000	21,100	22,200	1,500	3,200	3,400	28,600	27,900	28,300
Women	2,700	3,400	3,700	10,900	16,400	18,100	700	1,400	1,400	17,000	19,500	21,100
Social scientists	45,100	38,300	38,900	57,500	54,700	58,300	9,600	10,100	11,800	60,100	61,000	66,700
Men	37,400	30,800	30,900	47,200	39,800	41,100	8,500	8,700	10,100	40,800	42,100	46,600
Women	7,600	7,500	8,000	10,300	14,900	17,200	1,100	1,400	1,700	19,200	19,000	20,000

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Too few cases to estimate.
[3]Includes consulting; reporting, statistical work and computing; other; and no report.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314) and unpublished data.

See figures 3-6, 3-9 and 3-10.

Appendix table 3-9. Employed doctoral scientists and engineers by field, sex, and primary work activity: 1973–81

Field and sex	Total			Research			Development			Management of R&D			Management			Teaching			Other activities[2]		
	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981	1973	1979	1981
All S/E fields	220,400	313,800	343,500	63,000	84,700	101,700	8,500	15,000	18,400	32,900	43,000	32,600	13,300	29,200	27,700	80,000	91,900	105,000	22,800	49,900	58,200
Men	203,500	280,400	302,600	58,500	75,900	90,200	8,400	14,500	17,600	31,900	41,000	31,100	12,500	26,100	24,200	72,500	80,500	91,000	19,800	42,400	48,400
Women	17,000	33,300	40,900	4,500	8,800	11,500	200	500	800	1,000	2,000	1,500	800	3,100	3,500	7,500	11,400	13,900	3,000	7,500	9,700
Physical scientists	48,500	60,200	63,200	18,000	21,100	26,600	1,900	2,800	3,100	8,800	12,700	8,700	2,200	3,600	3,200	14,300	14,400	15,600	3,300	5,600	6,000
Men	46,600	57,000	59,400	17,400	20,000	25,000	1,900	2,700	2,900	8,600	12,300	8,500	2,100	3,400	3,000	13,400	13,400	14,500	3,100	5,300	5,600
Women	1,900	3,100	3,800	600	1,200	1,600	([3])	100	200	100	300	200	100	200	200	900	1,000	1,100	200	300	400
Mathematical scientists	12,100	15,300	15,600	2,500	3,100	3,000	200	500	400	500	500	300	500	1,300	1,000	8,100	8,900	9,600	500	1,000	1,300
Men	11,400	14,200	14,300	2,400	3,000	2,800	100	500	400	500	400	300	400	1,200	1,000	7,500	8,100	8,700	400	900	1,200
Women	800	1,100	1,300	100	100	200	([3])	([3])	([3])	([3])	([3])	([3])	([3])	100	([3])	600	800	900	100	100	100
Computer specialists	2,700	6,700	9,000	500	900	1,500	600	2,100	3,000	400	1,000	800	200	700	900	900	1,100	1,500	100	900	1,300
Men	2,600	6,400	8,300	500	900	1,400	500	2,000	2,800	400	900	800	200	700	900	900	1,100	1,400	100	800	1,200
Women	100	400	700	([3])	([3])	100	([3])	100	200	([3])	([3])	([3])	([3])	([3])	([3])	([3])	100	100	([3])	100	100
Environmental scientists[1]	10,300	14,600	16,000	3,500	5,200	6,000	100	400	300	2,000	2,400	2,400	600	1,200	1,200	3,100	3,000	3,600	1,000	2,400	2,500
Men	10,100	14,000	15,200	3,400	4,900	5,700	100	400	300	1,900	2,300	2,300	600	1,200	1,200	3,000	2,800	3,400	900	2,400	2,300
Women	300	600	900	100	300	400	([3])	([3])	([3])	([3])	100	100	([3])	100	100	100	100	200	([3])	100	200
Engineers	35,800	50,300	57,000	8,300	10,000	13,500	5,000	7,800	9,900	8,300	12,500	10,300	2,200	4,200	4,900	8,900	9,300	10,700	3,100	6,400	7,600
Men	35,600	49,700	56,200	8,200	9,800	13,300	4,900	7,700	9,700	8,300	12,400	10,200	2,200	4,200	4,900	8,800	9,300	10,600	3,100	6,300	7,500
Women	100	500	800	([3])	200	200	([3])	100	100	([3])	100	100	([3])	([3])	([3])	([3])	100	100	([3])	100	200
Life scientists	58,000	80,100	86,700	23,400	32,600	38,800	500	900	1,100	8,300	9,500	6,800	2,600	6,800	5,700	18,100	19,200	22,000	5,000	11,200	12,400
Men	51,900	68,900	73,500	20,600	27,800	32,400	400	700	900	8,000	8,800	6,300	2,400	6,000	4,800	15,900	15,900	18,400	4,600	9,800	10,700
Women	6,100	11,100	13,200	2,800	4,800	6,400	([3])	200	100	400	800	500	200	800	900	2,200	3,200	3,600	500	1,400	1,700
Psychologists	24,900	38,000	43,100	3,200	4,600	5,000	200	300	400	2,400	1,600	1,100	2,500	5,000	4,800	9,300	10,400	12,600	7,300	16,100	19,300
Men	20,100	28,800	31,200	2,700	3,600	3,800	100	200	300	2,100	1,300	800	2,200	4,000	3,500	7,500	8,000	9,300	5,400	11,700	13,400
Women	4,800	9,200	11,900	500	1,000	1,100	([3])	([3])	100	300	300	200	400	1,000	1,300	1,800	2,400	3,300	1,900	4,400	5,900
Social scientists	28,100	48,700	52,900	3,600	7,200	7,300	200	200	200	2,200	3,000	2,300	2,400	6,400	6,000	17,300	25,600	29,300	2,400	6,200	7,800
Men	25,200	41,400	44,500	3,200	6,000	5,900	100	200	200	2,000	2,500	1,900	2,300	5,500	5,100	15,400	21,900	24,700	2,100	5,300	6,700
Women	2,900	7,200	8,400	400	1,200	1,400	([3])	([3])	([3])	200	400	400	100	900	1,000	1,900	3,700	4,600	300	900	1,100

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Includes consulting; production/inspection; sales/professional services; reporting, statistical work, and computing; other; and no report.
[3]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977–81) and unpublished data.

See figure 3-9.

Appendix table 3-12. Doctoral intensity[1] of the science and engineering work force: 1976 and 1981

Field	1976	1981
All S/E fields	11.6	11.0
All scientists	19.7	17.3
Physical scientists	30.6	30.4
Chemists	28.1	28.4
Physicists & astronomers	36.7	35.4
Mathematical scientists	16.1	11.7
Mathematicians	19.4	14.5
Statisticians	10.3	6.0
Computer specialists	2.3	2.2
Environmental scientists	19.4	15.4
Earth scientists	17.9	15.3
Oceanographers	47.3	63.6
Atmospheric scientists	18.9	9.6
Life scientists	24.6	21.1
Biological scientists	30.8	24.2
Agricultural scientists	13.2	9.6
Medical scientists	32.8	53.0
Psychologists	29.1	32.8
Social scientists	17.7	23.4
Economists	18.1	16.4
Sociologists & anthropologists	21.0	18.3
Other social scientists	16.4	34.0
All engineers	3.7	3.8
Aeronautical engineers	NA	5.0
Chemical engineers	NA	9.0
Civil engineers	NA	2.9
Electrical & electronic engineers	NA	3.8
Mechanical engineers	NA	2.2
Other engineers	NA	4.1

[1] Employed doctoral scientists and engineers as a percent of all employed scientists and engineers.

NA: not available.

SOURCES: National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314); *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-81); and unpublished data.

See figure 3-8.

Appendix table 3-13. Distribution of employed scientists and engineers by field and minority group: 1981

Field	All S/E's	Minority scientists and engineers: All minorities	Blacks	Asians	Other minorities
		Number			
All S/E fields	3,134,100	159,400	64,100	83,500	11,800
Engineers	1,479,400	67,600	20,600	41,800	5,200
Mathematical scientists	132,900	10,000	5,200	4,100	700
Computer specialists	420,200	27,300	10,200	15,400	1,700
Life scientists	411,000	19,900	8,300	9,400	2,200
Physical scientists	229,500	13,800	5,000	8,500	300
Environmental scientists[1]	103,900	2,200	600	1,100	500
Psychologists	131,200	4,300	3,400	600	300
Social scientists	226,000	14,500	11,000	2,600	900
		Percent			
All S/E fields	100.0	5.1	2.0	2.7	0.4
Engineers	100.0	4.6	1.4	2.8	.4
Mathematical scientists	100.0	7.5	3.9	3.1	.5
Computer specialists	100.0	6.5	2.4	3.7	.4
Life scientists	100.0	4.8	2.0	2.3	.5
Physical scientists	100.0	6.0	2.2	3.7	.1
Environmental scientists[1]	100.0	2.1	.6	1.1	.5
Psychologists	100.0	3.3	2.6	.5	.2
Social scientists	100.0	6.4	4.9	1.2	.4

[1] Includes earth scientists, oceanographers, and atmospheric scientists.
[2] Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 3-12 and table 3-1 in text.

Appendix table 3-14. Field distribution of employed scientists and engineers by field and selected minority groups: 1981

Field	All S/E's		Black S/E's		Asian S/E's	
	Total employed	Percent	Total employed	Percent	Total employed	Percent
All S/E fields	3,134,100	100.0	64,100	100.0	83,500	100.0
Engineers	1,479,400	47.2	20,600	32.1	41,800	50.1
Mathematical scientists	132,900	4.2	5,200	8.1	4,100	4.9
Computer specialists	420,200	13.4	10,200	15.9	15,400	18.4
Life scientists	411,000	13.1	8,300	12.9	9,400	11.3
Physical scientists	229,500	7.3	5,000	7.8	8,500	10.2
Environmental scientists[1]	103,900	3.3	600	.9	1,100	1.3
Psychologists	131,200	4.2	3,400	5.3	600	.7
Social scientists	226,000	7.2	11,000	17.2	2,600	3.1

[1] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See table 3-1 in text.

Science Indicators—1982

Appendix table 3-15. Annual unemployment rates: 1976-81

(in percent)

Year	Total labor force	Professional and technical workers	All S/E's		Scientists		Engineers	
			Total	Doctoral	Total	Doctoral	Total	Doctoral
1976	7.7	3.2	1.9	NA	1.8	NA	1.9	NA
1977	7.0	3.0	NA	1.2	NA	1.3	NA	.6
1978	6.0	2.6	1.0	NA	1.2	NA	.8	NA
1979	5.8	2.4	NA	.9	NA	1.0	NA	.5
1980	7.1	2.5	1.0	NA	1.2	NA	.9	NA
1981	7.6	2.8	1.1	.8	1.2	.9	.9	.1

NA: Not available.

SOURCES: *Economic Report of the President, 1982,* p. 271; U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings,* (January, annual series); National Science Foundation, *U.S. Scientists and Engineers, 1980* (NSF 82-314); National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-81); and National Science Foundation, unpublished data.

See figure 3-13.

Science Indicators—1982

Appendix table 3-16. Unemployment rates for all scientists and engineers and doctoral scientists and engineers by field and sex: 1981

Field	All scientists and engineers			Doctoral scientists and engineers		
	Total	Men	Women	Total	Men	Women
All S/E fields	1.1	1.0	1.5	0.8	0.5	2.3
All scientists	1.2	1.1	1.4	.9	.7	2.4
Physical scientists	1.6	1.4	2.5	.8	.7	2.2
Chemists	1.6	1.4	2.9	.8	.7	2.1
Physicists & astronomers	1.9	2.0	.6	.8	.7	2.4
Other physical scientists	.4	.4	([1])	—	—	—
Mathematical scientists	.8	.5	2.1	.6	.6	1.4
Mathematicians	.9	.6	2.0	.7	.7	1.2
Statisticians	.8	.3	2.2	.2	([1])	1.8
Computer specialists	.6	.6	.4	.1	([1])	.4
Environmental scientists	2.5	2.4	2.8	.6	.5	1.1
Earth scientists	3.0	2.9	3.8	.7	.7	1.7
Oceanographers	([1])	([1])	([1])	.1	.1	([1])
Atmospheric scientists	.8	1.0	([1])	([1])	([1])	([1])
Life scientists	1.0	1.0	1.0	1.1	.7	3.3
Biological scientists	1.0	1.2	.7	1.7	1.1	4.2
Agricultural scientists	.8	.9	.4	.4	.4	1.6
Medical scientists	1.7	.7	6.0	.4	.2	1.3
Psychologists	1.5	1.0	2.3	1.1	1.1	1.2
Social scientists	1.6	1.4	2.1	.8	.3	3.0
Economists	1.4	1.1	2.8	.3	.4	([1])
Sociologists & anthropologists	1.2	1.0	1.6	1.4	.6	3.5
Other social scientists	1.9	1.8	2.3	.7	.2	3.5
All engineers	.9	.9	2.2	.1	.1	.5
Aeronautical engineers	.9	1.0	([1])	([1])	([1])	([1])
Chemical engineers	1.1	.9	3.9	.2	.2	1.8
Civil engineers	1.1	1.1	1.2	([1])	([1])	([1])
Electrical & electronic engineers	.8	.8	([1])	([1])	([1])	([1])
Mechanical engineers	.7	.7	([1])	([1])	([1])	([1])
Other engineers	1.0	.9	2.8	.1	.1	.8

[1] Too few cases to estimate.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981* (NSF 82-332) and unpublished data.

See figure 3-16.

Science Indicators—1982

Appendix table 3-17. S/E utilization rates for all scientists and engineers and for doctoral scientists and engineers by field and sex: 1981

Field	All scientists and engineers			Doctoral scientists and engineers		
	Total	Men	Women	Total	Men	Women
All S/E fields	88.2	88.6	86.0	90.7	91.2	87.4
All scientists	88.1	88.9	85.7	90.2	90.7	87.2
Physical scientists	82.4	82.6	78.0	89.8	90.0	86.1
Chemists	80.5	80.8	79.3	90.1	90.5	85.8
Physicists & astronomers	85.6	86.1	73.3	89.1	89.1	87.5
Other physical scientists	83.1	84.3	68.8	—	—	—
Mathematical scientists	89.0	90.2	83.0	89.9	89.9	90.2
Mathematicians	86.9	88.8	78.1	89.3	89.4	88.6
Statisticians	92.2	93.3	89.4	93.0	92.7	96.1
Computer specialists	93.6	96.9	85.6	99.1	99.1	98.7
Environmental scientists	82.6	82.8	80.3	95.1	95.1	94.4
Earth scientists	79.9	80.9	73.4	88.0	94.4	93.4
Oceanographers	92.5	91.2	99.6	97.4	97.7	95.6
Atmospheric scientists	90.5	88.4	100.0	97.5	97.4	98.8
Life scientists	91.6	91.6	92.7	93.8	94.4	90.2
Biological scientists	90.3	89.3	92.5	92.6	93.7	88.2
Agricultural scientists	93.3	92.7	97.5	92.6	92.8	86.2
Medical scientists	94.3	97.3	80.7	97.4	97.7	95.7
Psychologists	86.6	87.1	85.6	90.6	91.2	88.7
Social scientists	80.1	79.7	81.3	81.7	82.3	78.5
Economists	84.2	84.1	84.7	82.2	82.1	83.4
Sociologists & anthropologists	81.1	80.3	82.3	81.2	81.1	81.5
Other social scientists	75.4	74.6	77.8	81.6	82.8	75.3
All engineers	88.5	88.4	90.1	93.3	93.2	96.5
Aeronautical engineers	89.1	88.8	100.0	89.0	88.8	100.0
Chemical engineers	90.6	90.6	90.6	88.9	88.8	96.4
Civil engineers	91.7	91.7	92.1	93.5	93.5	91.7
Electrical & electronic engineers	92.4	92.4	92.1	94.2	94.2	98.6
Mechanical engineers	92.0	91.9	100.0	92.7	92.7	90.0
Other engineers	83.8	83.7	86.9	94.6	94.5	97.0

SOURCE: National Science Foundation, unpublished data.

See figures 3-15 and 3-16.

Science Indicators—1982

Appendix table 3-18. Average monthly salary offers to bachelor's degree candidates in selected fields: 1976/77–1981/82

Curriculum	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82
Business	$ 927	$ 993	$1,102	$1,218	$1,356	$1,477
Humanities	810	871	983	1,074	1,204	1,283
Social sciences	863	930	1,020	1,131	1,246	1,391
Engineering:						
Chemical	1,389	1,513	1,642	1,801	2,030	2,256
Civil	1,185	1,288	1,402	1,554	1,775	1,925
Electrical	1,245	1,367	1,520	1,690	1,882	2,064
Mechanical	1,286	1,404	1,536	1,703	1,908	2,098
Petroleum	1,512	1,653	1,793	1,987	2,221	2,539
Agricultural sciences	924	965	1,046	1,192	1,287	1,391
Biological sciences	882	1,036	1,017	1,159	1,268	1,375
Chemistry	1,102	1,191	1,332	1,459	1,637	1,751
Computer sciences	1,123	1,266	1,401	1,558	1,726	1,908
Mathematics	1,073	1,185	1,324	1,475	1,624	1,777

SOURCE: CPC Salary Survey, *Formal Report* (annual series), (Bethlehem, Pa.: College Placement Council).

See figure 3-17.

Science Indicators—1982

Appendix table 3-19. Average number of monthly salary offers to bachelor's degree candidates in selected fields: 1976/77–1981/82

Curriculum	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82
Business	3,649	4,565	4,796	4,805	4,376	4,175
Humanities	1,018	1,010	658	581	675	651
Social sciences	1,275	2,008	1,947	1,783	1,629	1,517
Engineering:						
Chemical	4,026	5,293	6,310	7,029	7,428	3,986
Civil	2,178	3,529	4,424	4,181	4,416	2,326
Electrical	6,106	8,599	10,742	11,120	10,768	9,976
Mechanical	5,446	8,082	10,030	10,637	10,673	7,338
Petroleum	506	663	717	762	1,445	1,090
Agricultural sciences	652	657	257	551	490	469
Biological sciences	238	313	244	222	215	169
Chemistry	331	340	379	427	409	262
Computer sciences	1,323	1,803	2,268	2,569	2,876	3,227
Mathematics	554	679	756	823	729	708

SOURCE: CPC Salary Survey, *Formal Report* (annual series), (Bethlehem, Pa.: College Placement Council).

Science Indicators—1982

Appendix table 3-20. Salaries and earnings of R&D scientists and engineers, production workers, and male professional and technical workers: 1970-81

Year	Median monthly salaries of R&D S/E's		Average hourly earnings of production workers		Annual earnings of male professional and technical workers	
	Dollars	Index (1970=100)	Dollars	Index (1970=100)	Dollars	Index (1970=100)
1970	$1,437	100.0	$3.23	100.0	$12,255	100.0
1971	1,512	105.2	3.45	106.8	12,518	102.1
1972	1,567	109.0	3.70	114.6	13,542	110.5
1973	1,632	113.6	3.94	122.0	14,306	116.7
1974	1,694	117.9	4.24	131.3	14,873	121.4
1975	1,828	127.2	4.53	140.2	15,796	128.9
1976	1,941	135.1	4.86	150.5	16,939	138.2
1977	2,060	143.4	5.25	162.5	18,244	148.7
1978	2,205	153.4	5.69	176.2	19,729	161.0
1979	2,370	164.9	6.16	190.7	21,269	173.6
1980	2,600	180.9	6.66	206.2	23,026	187.9
1981	2,869	199.7	7.25	224.5	NA	NA

NA = not available.

NOTE: Earnings of professional and technical workers are for full-time year-round employees. Earnings of production workers are for those on private (non-public) payrolls.

SOURCES: *Economic Report of the President, 1982,* p. 276; Batelle Columbus Laboratories, *National Survey of Compensation Paid Scientists and Engineers in Research and Development Activities* (1974, 1975, 1978 and 1981), Table 25; and U.S. Department of Labor, Bureau of Census, *Current Population Reports,* Series P–60, No. 120, Table 9 (November 1982).

Science Indicators—1982

Appendix table 3-21. High Technology Recruitment Index: 1970-82

[1961 = 100]

Year	Index
1970	60
1971	43
1972	63
1973	97
1974	101
1975	68
1976	88
1977	115
1978	139
1979	144
1980	138
1981	135
1982	104

SOURCE: Deutsch, Shea, and Evans, "High Technology Recruitment Index Year End Review and Forecast," (New York, 1983).

See figure 3-18.

Science Indicators—1982

Appendix table 3-22. High school seniors by number of years of mathematics and science coursework and type of curriculum: 1980

Amount of coursework	Mathematics			Science		
	Academic	General	Vocational	Academic	General	Vocational
Total, including those with no coursework	100	100	100	100	100	100
1 year or more	98	90	89	96	88	83
2 years or more	86	57	52	74	44	35
3 years or more	55	22	18	41	13	9

SOURCE: U.S. Department of Education, National Center for Education Statistics, *High School and Beyond: A Longitudinal Study for the 1980's,* 1981, p. 3.

See figure 3-20.

Science Indicators—1982

Appendix table 3-23. College-bound seniors by number of years of study for selected subjects: 1982

Years of study	Mathematics	Physical sciences	Biological sciences
	Percent		
None	0.2	8.5	4.8
One	1.7	31.7	60.9
Two	10.7	35.4	26.6
Three	26.2	19.4	5.3
Four	50.0	3.8	1.7
Five or more	11.2	1.2	.7
Total	100.0	100.0	100.0

NOTE: Detail may not add to totals because of rounding.

SOURCE: Based on Admissions Testing Program of the College Board, *National College-Bound Seniors, 1982* (Princeton, N.J.: Educational Testing Service, 1982), p. 14.

See figure 3-21.

Science Indicators—1982

Appendix table 3-24. Percent of high school seniors taking mathematics and science courses by type of course, sex, and racial/ethnic group: 1980

Course	All seniors	Sex: Male	Sex: Female	Racial/ethnic group: Hispanic	Black	White	American Indian or Alaskan Native	Asian or Pacific Islander
Algebra I	79	79	79	67	68	81	61	88
Algebra II	49	51	47	38	39	50	32	76
Geometry	56	58	55	39	38	60	34	79
Trigonometry	26	30	22	15	15	27	17	50
Calculus	8	10	6	4	5	8	5	22
Physics	19	26	14	15	19	20	17	35
Chemistry	37	39	35	26	28	39	24	59

SOURCE: U.S. Department of Education, National Center for Education Statistics, *High School and Beyond: A Longitudinal Study for the 1980's*, 1981, p. 3.

See figure 3-20.

Science Indicators—1982

Appendix table 3-25. Scholastic Aptitude Test (SAT) score averages for college-bound seniors by sex: 1970–82

Year	Verbal: Male	Verbal: Female	Verbal: Total	Mathematical: Male	Mathematical: Female	Mathematical: Total
1970	459	461	460	509	465	488
1971	454	457	455	507	466	488
1972	454	452	453	505	461	484
1973	446	443	445	502	460	481
1974	447	442	444	501	459	480
1975	437	431	434	495	449	472
1976	433	430	431	497	446	472
1977	431	427	429	497	445	470
1978	433	425	429	494	444	468
1979	431	423	427	493	443	467
1980	428	420	424	491	443	466
1981	430	418	424	492	443	466
1982	431	421	426	493	443	467

SOURCE: Admissions Testing Program of the College Board, *College-Bound Seniors* (annual series).

See figure 3-25.

Science Indicators—1982

Appendix table 3-26. Graduate Record Examination (GRE) scores by prospective graduate major: 1975/76-1980/81

Prospective graduate major	Aptitude type	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
				Science fields			
Physical sciences	V	501	515	519	519	480	511
	Q	622	633	636	630	628	628
Mathematical sciences	V	520	513	504	505	490	484
	Q	673	666	669	662	655	649
Engineering	V	471	463	459	468	453	449
	Q	654	657	657	660	656	655
Biological sciences	V	511	514	517	484	512	508
	Q	563	566	574	553	569	569
Behavioral sciences	V	502	512	517	512	509	506
	Q	493	503	512	509	509	511
Social sciences	V	510	499	490	487	483	481
	Q	496	490	487	485	484	482
				Nonscience fields			
Health	V	506	498	491	487	487	484
	Q	518	515	507	506	501	504
Education	V	468	458	450	451	448	448
	Q	460	451	450	449	448	449
Arts	V	512	509	507	503	499	493
	Q	485	483	483	483	485	481
Humanities	V	541	546	543	531	537	530
	Q	498	503	508	507	508	509

NOTE: V = verbal; Q–quantitative

SOURCE: Educational Testing Service, *A Summary of Data Collected from Graduate Record Examination Test-Takers* (Data Summary Reports #1-6) (Princeton, N.J.: Educational Testing Service, Inc.)

See figure 3-28.

Science Indicators—1982

Appendix table 3-27. Bachelor's and first-professional degrees awarded by field: 1960-81

Year	All fields	Science and engineering fields: S/E total	Physical sciences[1]	Engineering	Mathematical sciences[2]	Life sciences	Social sciences[3]	All other fields[4]
	Number							
1960	394,889	120,937	16,057	37,808	11,437	24,141	31,494	273,952
1961	401,784	121,660	15,500	35,866	13,127	23,900	33,267	280,124
1962	420,485	127,469	15,894	34,735	14,610	25,200	37,030	293,016
1963	450,592	135,964	16,276	33,458	16,128	27,801	42,308	314,628
1964	502,104	153,361	17,527	35,226	18,677	31,611	50,320	348,743
1965	538,930	164,936	17,916	36,795	19,668	34,642	55,715	373,994
1966	555,613	173,471	17,186	35,815	20,182	38,964	63,424	382,142
1967	594,862	187,849	17,794	36,188	21,530	39,408	72,929	407,013
1968	671,591	212,174	19,442	37,614	24,084	43,260	87,774	459,417
1969	769,683	244,519	21,591	41,553	28,263	48,713	104,399	525,164
1970	833,322	264,122	21,551	44,772	29,109	52,129	116,561	569,200
1971	884,386	271,176	21,549	45,387	27,306	51,461	125,473	613,210
1972	937,884	281,228	20,887	46,003	27,250	51,484	133,604	656,656
1973	980,707	295,391	20,809	46,989	27,528	59,485	140,579	685,316
1974	1,008,654	305,062	21,287	43,530	26,570	68,226	145,449	703,592
1975	987,922	294,920	20,896	40,065	23,385	72,710	137,864	693,002
1976	997,504	292,174	21,559	39,114	21,749	77,301	132,451	705,330
1977	993,008	288,543	22,616	41,581	20,729	78,472	125,143	704,465
1978	997,165	288,167	23,175	47,411	19,925	77,138	120,518	708,998
1979	1,000,562	288,625	23,363	53,720	20,670	75,085	115,787	711,937
1980	1,010,777	291,983	23,661	59,240	22,686	71,617	114,779	718,794
1981[5]	1,019,237	294,867	24,175	64,068	26,406	68,086	112,133	724,370
	Percent							
1960	100	31	4	10	3	6	8	69
1961	100	30	4	9	3	6	8	70
1962	100	30	4	8	4	6	9	70
1963	100	30	4	7	4	6	9	70
1964	100	31	4	7	4	6	10	69
1965	100	31	3	7	4	7	10	69
1966	100	31	3	6	4	7	11	69
1967	100	32	3	6	4	7	12	68
1968	100	32	3	6	4	6	13	68
1969	100	32	3	5	4	6	14	68
1970	100	32	3	5	4	6	14	68
1971	100	31	2	5	3	6	14	69
1972	100	30	2	5	3	6	14	70
1973	100	30	2	5	3	6	14	70
1974	100	30	2	4	3	7	14	70
1975	100	30	2	4	2	7	14	70
1976	100	29	2	4	2	8	13	71
1977	100	29	2	4	2	8	13	71
1978	100	29	2	5	2	8	12	71
1979	100	29	2	5	2	8	12	71
1980	100	29	2	6	2	7	11	71
1981	100	29	3	7	3	7	12	71

[1] Including environmental sciences.
[2] Including statistics and computer specialties.
[3] Excluding history and including psychology.
[4] Including first-professional degrees such as M.D., D.D.S., D.V.M., and J.D. degrees.
[5] Number of first-professional degrees estimated for 1981.

NOTE: Percents may not add to 100 because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Degrees: 1950-80* (NSF 82-307) and unpublished data.

See figure 3-25.

Appendix table 3-28. Master's degrees awarded by field: 1960-81

Year	All fields	Science and engineering fields: Total	Physical sciences[1]	Engineering	Mathematical sciences[2]	Life sciences	Social sciences[3]	All other fields
	Number							
1960	74,497	20,012	3,387	7,159	1,765	3,751	3,950	54,485
1961	78,269	22,786	3,799	8,178	2,238	4,085	4,486	55,483
1962	84,889	25,146	3,929	8,909	2,680	4,672	4,956	59,743
1963	91,418	27,367	4,132	9,635	3,323	4,718	5,559	64,051
1964	101,122	30,271	4,567	10,827	3,603	5,357	5,917	70,851
1965	112,195	33,835	4,918	12,056	4,294	5,978	6,589	78,360
1966	140,772	38,083	4,992	13,678	5,010	6,666	7,737	102,689
1967	157,892	41,800	5,412	13,885	5,733	7,465	9,305	116,092
1968	177,150	45,425	5,508	15,188	6,081	8,315	10,333	131,725
1969	194,414	48,425	5,911	15,243	6,735	8,809	11,727	145,989
1970	209,387	49,318	5,948	15,597	7,107	8,590	12,076	160,069
1971	231,486	50,624	6,386	16,347	6,789	8,320	12,782	180,862
1972	252,774	53,567	6,307	16,802	7,186	8,914	14,358	199,207
1973	264,525	54,234	6,274	16,758	7,146	9,080	14,976	210,291
1974	278,259	54,175	6,087	15,393	7,116	9,605	15,974	224,084
1975	293,651	53,852	5,830	15,434	6,637	9,618	16,333	239,799
1976	313,001	54,747	5,485	16,170	6,466	9,823	16,803	258,254
1977	318,241	56,731	5,345	16,889	6,496	10,707	17,294	261,510
1978	312,816	56,237	5,576	17,105	6,421	10,711	16,514	256,579
1979	302,075	54,456	5,464	16,193	6,101	10,719	15,979	247,619
1980	299,095	54,391	5,233	16,846	6,515	10,278	15,519	244,704
1981	296,798	54,811	5,300	17,373	6,787	9,731	15,620	241,984
	Percent							
1960	100	27	5	10	2	5	5	73
1961	100	29	5	10	3	5	6	71
1962	100	30	5	11	3	6	6	70
1963	100	30	5	11	4	5	6	70
1964	100	30	5	11	4	5	6	70
1965	100	30	4	11	4	5	6	70
1966	100	27	4	10	4	5	6	73
1967	100	26	3	9	4	5	6	74
1968	100	26	3	9	3	5	6	74
1969	100	25	3	8	4	5	6	75
1970	100	24	3	7	3	4	6	76
1971	100	22	3	7	3	4	6	78
1972	100	21	3	7	3	4	6	79
1973	100	21	2	6	3	3	6	79
1974	100	19	2	6	3	3	6	81
1975	100	18	2	5	2	3	6	82
1976	100	17	2	5	2	3	5	83
1977	100	18	2	5	2	3	5	82
1978	100	18	2	5	2	3	5	82
1979	100	18	2	5	2	4	5	82
1980	100	18	2	6	2	3	5	82
1981	100	18	2	6	2	3	5	82

[1] Including environmental sciences.
[2] Including statistics and computer specialties.
[3] Excluding history and including psychology.

NOTE: Percents may not add to 100 because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Degrees: 1950-80* (NSF 82-307) and unpublished data.

See figure 3-26.

Appendix table 3-29. Doctoral degrees awarded by field: 1960-1981

Year	All fields	Science and engineering fields: Total	Physical sciences[1]	Engineering	Mathematical sciences[2]	Life sciences	Social sciences[3]	All other fields[4]
	Number							
1960	9,733	6,263	1,861	794	291	1,660	1,657	3,470
1961	10,413	6,721	1,993	940	332	1,682	1,774	3,692
1962	11,500	7,438	2,097	1,216	388	1,867	1,870	4,062
1963	12,729	8,220	2,428	1,357	483	1,976	1,976	4,509
1964	14,325	9,224	2,527	1,664	588	2,219	2,226	5,101
1965	16,340	10,476	2,865	2,074	685	2,539	2,313	5,864
1966	17,949	11,458	3,059	2,301	769	2,711	2,618	6,491
1967	20,403	12,982	3,503	2,604	830	2,966	3,079	7,421
1968	22,936	14,448	3,681	2,855	971	3,511	3,430	8,488
1969	25,743	16,039	3,935	3,265	1,070	3,815	3,954	9,704
1970	29,498	17,743	4,403	3,434	1,225	4,165	4,516	11,755
1971	31,867	18,948	4,501	3,498	1,238	4,556	5,155	12,919
1972	33,044	19,009	4,257	3,503	1,281	4,454	5,514	14,035
1973	33,756	19,001	4,078	3,364	1,233	4,503	5,823	14,755
1974	33,047	18,313	3,765	3,147	1,211	4,304	5,886	14,734
1975	32,951	18,358	3,710	3,002	1,147	4,402	6,097	14,593
1976	32,946	17,864	3,506	2,834	1,003	4,361	6,110	15,082
1977	31,718	17,418	3,415	2,643	964	4,266	6,130	14,300
1978	30,873	17,048	3,234	2,423	959	4,369	6,063	13,825
1979	31,235	17,245	3,320	2,490	979	4,501	5,955	13,990
1980	31,016	17,199	3,149	2,479	962	4,716	5,893	13,817
1981	31,319	17,623	3,208	2,528	960	4,783	6,144	13,696
	Percent							
1960	100	64	19	8	3	17	17	36
1961	100	65	19	9	3	16	17	35
1962	100	65	18	11	3	16	16	35
1963	100	65	19	11	4	16	16	35
1964	100	64	18	12	4	15	16	36
1965	100	64	18	13	4	16	14	36
1966	100	64	17	13	4	15	15	36
1967	100	64	17	13	4	15	15	36
1968	100	63	16	12	4	15	15	37
1969	100	62	15	13	4	15	15	38
1970	100	60	15	12	4	14	15	40
1971	100	59	14	11	4	14	16	41
1972	100	58	13	11	4	13	17	42
1973	100	56	12	10	4	13	17	44
1974	100	55	11	10	4	13	18	45
1975	100	56	11	9	3	13	19	44
1976	100	54	11	9	3	13	19	46
1977	100	55	11	8	3	13	19	45
1978	100	55	10	8	3	14	20	45
1979	100	55	11	8	3	14	19	45
1980	100	55	10	8	3	15	19	45
1981	100	56	10	8	3	15	20	44

[1] Includes environmental sciences.
[2] Includes computer specialties.
[3] Includes psychology.
[4] Excludes first-professional degrees such as M.D., D.D.S., D.V.M., and J.D.

SOURCES: National Academy of Sciences and National Science Foundation, unpublished data.

See figure 3-27.

Science Indicators—1982

Appendix table 3-30. Characteristics of 1978 and 1979 bachelor's degree recipients by field and labor force status: 1980

Field	Total	In the labor force						Outside the labor force	Full-time graduate students[1]
		Total labor force	Employed			Unemployed but seeking employment			
			Total employed	Employed in S/E	Employed outside S/E				
All S/E fields	460,300	445,100	429,100	226,600	202,500	16,000		15,100	138,400
Physical scientists	19,300	18,500	18,100	14,000	4,100	400		700	14,600
Mathematical scientists	20,100	19,500	18,400	11,700	7,200	600		600	4,500
Computer specialists	15,100	15,100	14,800	13,800	900	300		100	900
Environmental scientists[2]	15,500	14,900	14,100	8,300	5,800	800		600	4,500
Engineers	109,500	108,60	107,200	99,300	7,800	1,500		800	9,800
Life scientists	101,500	97,500	92,400	48,600	43,800	5,100		4,000	51,200
Psychologists	68,700	65,300	63,200	11,500	51,800	2,100		3,400	19,300
Social scientists	110,600	105,700	100,500	19,500	81,000	5,200		4,900	33,600

[1] Not included in totals.
[2] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Based on National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1980* (NSF 82-313), tables B-1, B-4, B-19 and B-22 and unpublished data.

See figures 3-29, 3-30, and 3-31.

Science Indicators—1982

Appendix table 3-31. Characteristics of 1978 and 1979 master's degree recipients by field and labor force status: 1980

Field	Total	In the labor force					Outside the labor force	Full-time graduate students[1]
		Total labor force	Employed			Unemployed but seeking employment		
			Total employed	Employed in S/E	Employed outside S/E			
All S/E fields	86,000	83,500	81,600	66,700	15,000	1,900	2,600	24,100
Physical scientists	4,400	4,300	4,200	3,600	600	100	100	2,700
Mathematical scientists	5,400	5,200	5,000	3,700	1,300	200	200	1,100
Computer specialists	5,700	5,500	5,500	5,100	400	(2)	200	400
Environmental scientists[3]	4,200	4,100	4,000	3,500	500	100	100	1,000
Engineers	28,600	28,300	28,100	26,700	1,400	200	300	4,600
Life scientists	15,400	15,200	14,800	11,700	3,100	400	300	6,300
Psychologists	11,900	10,800	10,400	7,200	3,200	400	1,100	4,300
Social scientists	10,500	10,200	9,600	5,200	4,400	600	300	3,600

[1] Not included in totals.
[2] Too few cases to estimate.
[3] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Based on National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1980* (NSF 82-313), tables B-10, B-13, B-28 and B-31; and unpublished data.

See figures 3-30 and 3-31.

Science Indicators—1982

Appendix table 3-32. Characteristics of 1979 doctoral degree recipients by field and labor force status: 1981

Field	Total	In the labor force							Outside the labor force
		Labor force	Employed					Unemployed but seeking employment	
			Total employed	Employed in S/E	Employed outside S/E	Postdoctorates			
All S/E fields	15,900	15,700	15,500	12,400	700	2,300		200	200
Physical scientists	2,100	2,100	2,100	1,500	100	500		(1)	(1)
Mathematical scientists	700	700	700	700	(1)	(1)		(1)	(1)
Computer specialists	600	600	600	600	(1)	(1)		(1)	(1)
Environmental scientists[2]	700	700	700	700	(1)	(1)		(1)	(1)
Engineers	2,100	2,100	2,100	2,000	(1)	(1)		(1)	(1)
Life scientists	4,400	4,300	4,300	2,600	100	1,600		100	100
Psychologists	2,800	2,800	2,800	2,500	200	100		(1)	(1)
Social scientists	2,500	2,400	2,300	1,900	400	100		100	100

[1] Too few cases to estimate.
[2] Includes earth scientists, oceanographers and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 3-31.

Science Indicators—1982

Appendix table 3-33. In-field employment rates of 1978 and 1979 S/E bachelor's and master's degree graduates by field in 1980

Field	Bachelor's	Master's
	Percent	
All fields	43.6	72.6
Physical sciences	46.2	62.6
Mathematical sciences	49.6	61.9
Computer specialties	90.5	82.3
Environmental sciences	37.2	75.6
Engineering	88.0	86.9
Life sciences	39.2	71.6
Psychology	14.3	64.4
Social sciences	11.2	94.0

NOTE: In-field employment rate = $\frac{\text{Number employed in field of degree}}{\text{Total employment.}}$

SOURCE: National Science Foundation, unpublished data.

Science Indicators—1982

Appendix table 3-34. Ratio of recent science and engineering degree recipients[1] employed in field relative to graduates in field who entered the labor force by degree level

Field	Bachelor's[2]	Master's[2]	Doctorates[3]
All S/E fields	0.51	0.80	0.92
Chemistry	.95	.85	1.02
Physics	.39	.67	.71
Mathematics	.18	.41	.86
Computer specialties	2.18	1.52	3.33
Environmental sciences	.43	.88	1.18
Engineering	.98	.95	.85
Life sciences	.42	.73	1.00
Psychology	.08	.64	.84
Social sciences	.20	.43	.84

[1] Excludes full-time graduate students and those on postdoctoral appointments.

[2] 1978 and 1979 graduates in 1980.

[3] 1977 graduates in 1979.

SOURCE: Based on National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1980* (NSF 82-313), Tables B-4, B-8, B-13, B-17, B-22, B-26, B-31, and B-35; and unpublished data.

See figure 3-19.

Science Indicators—1982

Appendix table 4-1. Scientists and engineers in business and industry by primary work activity and field: 1976

	Total industry	Research and development[1]				Management of R&D	Other management	Production/ inspection	Other[2]
		Total	Basic research	Applied research	Development				
All fields	1,274,900	377,400	14,200	56,200	307,000	120,600	247,600	200,500	328,800
All scientists	429,600	100,800	10,000	32,000	58,800	41,800	70,300	56,600	160,100
Physical scientists	100,600	38,100	5,900	15,200	17,100	17,000	13,500	17,500	14,500
Chemists	78,400	29,900	4,500	11,300	14,100	12,300	9,600	16,000	10,600
Physicists and astronomers	17,700	6,800	1,100	3,100	2,600	3,600	3,400	1,000	2,900
Other physical scientists	4,500	1,400	300	800	300	1,100	500	500	1,000
Mathematical scientists	27,800	6,100	500	2,800	3,100	3,000	6,900	3,300	8,500
Mathematicians	22,300	5,300	300	2,100	3,000	2,700	6,700	2,700	4,900
Statisticians	5,600	800	200	400	200	300	200	500	3,800
Computer specialists	142,000	33,600	900	1,500	31,200	6,100	12,900	6,600	82,800
Environmental scientists	29,000	7,500	700	4,600	2,200	3,100	4,500	3,600	10,300
Earth scientists	26,400	7,200	600	4,400	2,200	3,000	4,500	3,200	8,500
Oceanographers	500	200	(3)	200	(3)	(3)	(3)	(3)	300
Atmospheric scientists	2,100	100	700	(3)	(3)	100	(3)	300	1,600
Life scientists	72,300	12,100	1,900	5,400	4,800	7,700	15,300	19,400	17,800
Biological scientists	23,600	5,800	1,300	2,600	1,900	3,400	2,400	5,300	6,700
Agricultural scientists	42,300	4,400	100	2,100	2,200	2,700	11,400	13,600	10,200
Medical scientists	6,400	2,000	500	800	600	1,500	1,500	500	900
Psychologists	13,700	1,700	(3)	1,400	300	1,800	1,800	100	8,300
Social scientists	44,200	1,600	100	1,400	100	3,300	15,300	6,200	17,800
Economists	18,600	1,300	100	1,100	100	1,600	5,600	2,500	7,600
Sociologists and anthropologists	6,800	200	(3)	200	(3)	300	2,900	200	3,200
Other social scientists	18,800	100	(3)	100	(3)	1,400	6,800	3,600	6,900
All engineers	845,300	276,600	4,200	24,200	248,200	78,800	177,300	143,900	168,700
Aeronautical engineers	24,800	12,700	500	1,700	10,500	4,200	1,500	1,800	4,600
Chemical engineers	53,400	25,800	700	3,100	22,100	4,100	7,200	9,200	7,100
Civil engineers	68,200	17,600	300	700	16,600	1,900	16,300	14,900	17,500
Electrical engineers	145,400	70,800	900	5,000	65,000	13,000	16,200	20,400	25,000
Mechanical engineers	166,700	77,300	700	4,000	72,600	11,900	24,100	26,000	27,400
Other engineers	386,800	72,500	1,200	9,800	61,500	43,800	112,000	71,700	86,800

[1]Excludes R&D management.

[2]Includes consulting; teaching; sales/professional services; reporting, statistical work, computing; other and no report.

[3]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers* (NSF 82-314), pp. 174–181.

Science Indicators—1982

Appendix table 4-2. Scientists and engineers in business and industry by primary work activity and field: 1981

	Total industry	Research and development[1]				Management of R&D	Other management	Production/ inspection	Other[2]
		Total	Basic research	Applied research	Development				
All fields	1,872,900	542,200	24,600	74,600	443,000	144,400	287,100	325,900	573,300
All scientists	728,600	156,800	17,900	45,500	93,400	50,400	87,100	96,200	338,100
Physical scientists	122,000	49,700	6,400	18,800	24,600	16,500	14,200	24,400	17,200
Chemists	90,000	36,700	4,200	13,500	19,000	9,900	10,200	21,300	11,900
Physicists and astronomers	22,900	9,800	1,800	4,400	3,700	5,000	3,700	1,300	3,100
Other physical scientists	9,100	3,300	400	900	1,900	1,600	400	1,900	1,900
Mathematical scientists	47,500	9,100	600	2,900	5,600	4,100	7,300	3,500	23,500
Mathematicians	30,500	7,500	400	2,000	5,100	3,400	6,300	2,900	10,400
Statisticians	17,000	1,600	200	900	500	700	1,000	600	13,100
Computer specialists	315,400	55,200	2,300	4,600	48,300	10,800	17,700	12,400	219,300
Environmental scientists	52,200	16,000	2,000	8,200	5,800	2,900	5,900	9,700	17,700
Earth scientists	44,800	14,300	1,500	7,600	5,200	2,700	5,600	8,200	14,000
Oceanographers	500	300	200	(3)	(3)	(3)	(3)	100	100
Atmospheric scientists	7,000	1,400	200	600	600	200	400	1,400	3,600
Life scientists	117,600	20,800	4,800	7,900	8,200	9,600	25,600	38,200	23,400
Biological scientists	41,500	13,400	4,100	5,000	4,300	4,100	4,800	10,100	9,100
Agricultural scientists	71,800	6,100	500	2,800	2,800	4,300	20,600	27,000	13,800
Medical scientists	4,400	1,300	200	100	1,100	1,100	200	1,100	700
Psychologists	20,200	1,900	300	1,200	500	2,000	2,700	2,000	11,600
Social scientists	53,600	4,100	1,600	2,000	500	4,600	13,700	6,000	25,200
Economists	28,700	2,200	900	1,300	100	2,500	5,100	4,300	14,600
Sociologists and anthropologists	9,700	900	200	600	100	800	3,700	600	3,700
Other social scientists	15,200	1,000	500	200	300	1,300	4,900	1,000	7,000
All engineers	1,144,300	385,400	6,700	29,100	349,600	94,000	200,000	229,700	235,200
Aeronautical engineers	32,200	16,500	400	1,900	14,200	3,600	2,200	3,500	6,400
Chemical engineers	69,900	33,100	800	2,500	29,900	4,900	6,300	16,000	9,600
Civil engineers	120,400	29,500	700	1,300	27,500	4,100	24,000	25,000	37,800
Electrical engineers	222,000	110,400	1,300	6,900	102,200	16,400	17,800	40,300	37,100
Mechanical engineers	212,100	101,900	1,100	5,500	95,300	12,400	26,300	37,500	34,000
Other engineers	487,800	93,900	2,400	11,000	80,600	52,500	123,200	107,500	110,900

[1]Excludes R&D management.
[2]Includes consulting; teaching; sales/professional services; reporting, statistical work, computing; other; and no report.
[3]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 4-1.

Appendix table 4-3. Recent science and engineering degree recipients finding employment in business and industry by degree level and field for selected years

Field	Bachelor's degree recipients				Master's degree recipients				Doctorate recipients			
	1974 & 75 in 1976		1978 & 79 in 1980		1974 & 75 in 1976		1978 & 79 in 1980		1977 & 78 in 1979		1979 & 80 in 1981	
	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry
All fields	407,000	224,500	429,100	279,100	81,300	30,600	81,600	42,600	32,000	7,000	32,800	8,700
All scientists	323,700	158,400	322,000	185,100	53,800	12,800	53,500	21,300	27,900	4,100	28,600	6,000
Physical scientists	17,400	10,200	18,100	12,300	6,400	2,500	4,200	2,800	4,500	2,000	4,700	1,900
Mathematical scientists	29,500	17,100	18,900	13,400	5,700	1,600	5,000	2,400	1,200	100	1,300	200
Computer specialists	9,000	6,400	14,800	12,200	4,100	2,500	5,500	4,400	1,000	600	1,000	500
Environmental scientists[1]	4,600	2,100	14,100	9,000	1,400	700	4,100	2,500	1,500	400	1,600	600
Life scientists	80,500	39,100	92,400	47,400	13,400	2,900	14,800	4,600	8,200	800	8,900	800
Psychologists	64,100	27,200	63,200	31,300	9,200	1,000	10,400	2,300	5,300	400	5,600	1,200
Social scientists	118,800	56,300	100,500	59,500	13,600	1,700	9,600	2,400	6,400	300	5,500	900
All engineers	83,200	66,100	107,200	94,000	27,500	17,700	28,100	21,300	4,100	2,300	4,200	2,700

[1]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1980* (NSF 82-313), pp. 14, 30, 46–62, and unpublished data.

See figure 4-2.

Science Indicators—1982

Appendix table 4-4. Doctoral scientists and engineers in business and industry by primary work activity and field: 1981

	Total industry	Research and development				Management of R&D	Other management	Production/ inspection	Other[1]
		Total	Basic research	Applied research	Development				
All fields	99,000	43,600	6,300	21,800	15,400	18,500	6,100	2,700	28,100
All scientists	67,400	27,500	5,600	15,400	6,500	11,800	3,800	1,800	22,500
Physical scientists	27,400	15,400	3,700	9,100	2,600	6,500	1,100	800	3,600
Chemists	22,300	11,800	2,800	7,100	1,900	5,800	900	700	3,100
Physicists and astronomers	5,200	3,600	900	2,000	700	700	200	100	600
Mathematical scientists	1,600	700	(2)	400	200	100	(2)	(2)	800
Mathematicians	1,200	500	(2)	300	200	(2)	100	(2)	600
Statisticians	500	200	(2)	100	(2)	(2)	(2)	(2)	300
Computer specialists	5,200	3,300	200	600	2,500	600	300	(2)	1,000
Environmental scientists	4,800	1,500	300	1,100	100	800	700	100	1,700
Earth scientists	4,200	1,300	200	1,000	100	700	600	100	1,500
Oceanographers	200	100	(2)	(2)	(3)	(2)	(2)	(2)	100
Atmospheric scientists	400	200	100	100	(3)	100	(2)	(2)	100
Life scientists	13,500	4,300	1,200	2,500	700	3,300	700	700	4,500
Biological scientists	5,300	2,300	800	1,100	300	1,400	200	200	1,200
Agricultural scientists	3,500	800	200	500	100	800	300	300	1,300
Medical scientists	4,700	1,300	200	800	200	1,100	200	100	2,000
Psychologists	10,100	1,000	100	700	200	200	400	(2)	8,500
Social scientists	4,700	1,200	100	900	200	500	400	100	2,500
Economists	2,200	700	100	600	(2)	300	200	(2)	1,000
Sociologists and anthropologists	500	100	(2)	100	(2)	(2)	100	100	200
Other social scientists	2,100	400	(2)	300	100	200	100	100	1,300
All engineers	31,700	16,100	700	6,500	8,900	6,700	2,300	900	5,700
Aeronautical engineers	1,100	500	(2)	300	300	300	200	(2)	100
Chemical engineers	5,300	3,200	100	1,600	1,500	900	400	200	600
Civil engineers	2,500	700	(2)	200	400	100	300	(2)	1,400
Electrical engineers	6,200	3,300	100	1,100	2,100	1,700	400	100	700
Mechanical engineers	2,600	1,500	100	400	1,000	400	200	100	400
Other engineers	13,900	7,000	400	3,000	3,600	3,200	1,000	500	2,200

[1] Includes consulting; teaching; sales/professional services; reporting, statistical work, computing; other and no report.
[2] Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981, Detailed Statistical Tables* (NSF 82-332), pp. 41–46.

See figure 4-3.

Science Indicators—1982

Appendix table 4-5. Concentration ratios[1] of employed scientists and engineers for selected manufacturing industries: 1980

Industry	Total	Scientists	Engineers
Total manufacturing	1.0	1.0	1.0
Durable goods	1.3	.7	1.4
Lumber and wood products	.1	.3	.1
Furniture	.2	.1	.2
Stone, clay, and glass	.5	.5	.4
Primary metals	.6	.6	.6
Fabricated metal products	.5	.3	.6
Machinery	1.5	.7	1.7
Electrical machinery	2.2	1.1	2.5
Transportation equipment	2.2	1.3	2.4
Instruments	1.7	1.1	1.9
Misc. manufacturing	.3	.3	.3
Nondurable goods	.6	1.4	.4
Food and kindred products	.3	.9	.2
Tobacco products	.4	1.2	.2
Textiles	.2	.3	.2
Apparel	.1	.1	.1
Paper and allied products	.5	.7	.5
Printing and publishing	.1	.3	.1
Chemicals	2.2	6.4	1.2
Refined petroleum products	1.7	2.3	1.5
Rubber and plastic products	.6	.9	.6
Leather products	.1	.1	.1

[1]A concentration ratio relates each industry's share of science and engineering employment to its share of total (i.e., S/E and non-S/E) employment. That is: $C_i = (S_i/S)/(E_i/E)$, where C_i is the concentration ratio for industry i, S_i is the number of scientists and engineers in industry i, S is the total number of scientists and engineers in the sector (manufacturing), E_i is the total employment in industry i, and E is the total employment in the sector.

SOURCE: National Science Foundation, *Changing Employment Patterns of Scientists, Engineers and Technicians in Manufacturing Industries: 1977–1980* (NSF 82-331), p. 48.

See figure 4-4.

Science Indicators—1982

Appendix table 4-6. Expenditures for industrial R & D by source of funds: 1960–83

[Millions of dollars]

Year	Current dollars			Constant 1972 dollars[1]		
	Total	Company[2]	Federal Government	Total	Company[2]	Federal Government
1960	$10,509	$ 4,428	$ 6,081	$15,297	$ 6,445	$ 8,852
1961	10,908	4,668	6,240	15,733	6,733	9,000
1962	11,464	5,029	6,435	16,237	7,122	9,113
1963	12,630	5,360	7,270	17,622	7,479	10,144
1964	13,512	5,792	7,720	18,569	7,959	10,609
1965	14,185	6,445	7,740	19,077	8,667	10,409
1966	15,548	7,216	8,332	20,258	9,401	10,855
1967	16,385	8,020	8,365	20,725	10,144	10,581
1968	17,429	8,869	8,560	21,116	10,745	10,371
1969	18,308	9,857	8,451	21,094	11,357	9,737
1970	18,067	10,288	7,779	19,756	11,250	8,506
1971	18,320	10,654	7,666	19,081	11,097	7,985
1972	19,552	11,535	8,017	19,552	11,535	8,017
1973	21,249	13,104	8,145	20,094	12,391	7,702
1974	22,887	14,667	8,220	19,889	12,745	7,143
1975	24,187	15,582	8,605	19,229	12,387	6,841
1976	26,997	17,436	9,561	20,400	13,175	7,225
1977	29,825	19,340	10,485	21,297	13,809	7,487
1978	33,304	22,115	11,189	22,142	14,702	7,439
1979	38,226	25,708	12,518	23,391	15,731	7,660
1980	44,505	30,476	14,029	24,914	17,060	7,853
1981 (prel.)	51,830	35,362	16,468	26,511	18,087	8,423
1982 (est.)	57,850	39,325	18,525	27,918	18,977	8,940
1983 (est.)	64,250	43,575	20,675	29,461	19,980	9,480

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Includes all sources other than the Federal Government.

NOTE: Detail may not add to totals because of rounding.

SOURCES: 1960–64: National Science Foundation, *National Patterns of Science and Technology Resources, 1981* (NSF 81-311),p. 21; 1965–76: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319), p. 24; 1977–83: National Science Foundation, unpublished tabulations.

See figure 4-5.

Science Indicators—1982

Appendix table 4-7. R & D expenditures, by industry: 1960–81

Industry	1960	1962	1964	1966	1968	1970	1972	1974	1976	1978	1979	1980	1981
	Millions of current dollars												
Total	$10,509	$11,464	$13,512	$15,548	$17,429	$18,067	$19,552	$22,887	$26,997	$33,304	$33,226	$44,505	$51,830
Food and kindred products	104	121	144	164	184	230	259	298	355	472	528	620	719
Textiles and apparel	38	28	32	51	58	58	61	69	82	89	101	115	124
Lumber, wood products, and furniture	10	10	12	12	20	52	64	84	107	126	139	148	167
Paper and allied products	56	65	77	117	144	178	189	237	313	387	445	495	570[1]
Chemicals and allied products	980	1,175	1,284	1,407	1,589	1,773	1,932	2,450	3,017	3,580	4,038	4,636	5,325
Industrial chemicals	666	738	865	918	981	1,031	1,031	1,299	1,524	1,798	1,962	2,197	2,553
Drugs and medicines	162	195	234	308	398	485	607	807	1,091	1,308	1,517	1,777	2,000[1]
Other chemicals	152	242	185	181	210	257	294	344	401	474	559	662	770[1]
Petroleum refining and extraction	296	310	393	371	437	515	468	622	767	1,060	1,262	1,552	1,920[1]
Rubber products	121	141	158	168	223	276	377	469	502	493	577	656	800[1]
Stone, clay, and glass products	88	96	109	117	142	167	183	217	263	324	356	406	470[1]
Primary metals	177	171	195	232	251	275	277	358	506	560	634	728	889
Ferrous metals and products[2]	102	97	116	139	135	149	146	181	256	314	375	443	560[1]
Nonferrous metals and products	75	74	79	93	115	126	130	177	250	246	259	285	330[1]
Fabricated metal products	145	146	148	154	183	207	253	313	358	384	455	550	638
Nonelectrical machinery	949	914	1,015	1,217	1,483	1,729	2,158	2,985	3,487	4,283	4,825	5,901	6,800
Office, computing, and accounting machines	(3)	(3)	(3)	(3)	(3)	(3)	1,456	2,103	2,402	2,883	3,214	3,962	4,510[1]
Electrical equipment	2,532	2,639	2,972	3,626	4,083	4,220	4,680	5,011	5,636	6,507	7,824	9,175	10,466
Radio and TV receiving equipment	(4)	(4)	(4)	47	55	70	48	51	52	130	245	556	600[1]
Electronic components	(3)	(3)	(3)	(3)	(3)	(3)	330	489	691	902	1,169	1,547	1,659
Communication equipment and communication	1,324	1,591	1,872	2,249	2,520	2,604	2,583	2,424	2,511	2,999	3,635	4,024	4,737
Other electrical equipment	1,208	1,048	1,100	1,330	1,508	1,546	1,719	2,047	2,382	2,476	2,775	3,048	3,470[1]
Motor vehicles and other transportation equipment	884	999	1,182	1,344	1,499	1,591	2,010	2,476	2,872	4,010	4,668	5,117	5,087
Motor vehicles and motor vehicle equipment	(3)	(3)	(3)	(3)	(3)	(3)	1,954	2,389	2,778	3,879	4,509	4,955	4,929
Other transportation equipment	(3)	(3)	(3)	(3)	(3)	(3)	56	87	94	131	159	162	160[1]
Aircraft and missiles	3,514	4,042	5,078	5,526	5,765	5,219	4,950	5,278	6,339	7,536	8,041	9,198	11,702
Professional and scientific instruments	329	309	331	468	663	744	838	1,075	1,331	1,998	2,505	3,029	3,685
Scientific and mechanical measuring instruments	160	101	74	87	118	131	163	221	325	670	950	1,352	1,680[1]
Optical, surgical, photographic, and other instruments	169	208	257	381	545	613	675	854	1,007	1,328	1,555	1,677	2,000[1]
Other manufacturing industries	119	65	65	77	101	128	146	177	217	266	288	364	393[1]
Nonmanufacturing industries	168	234	319	497	603	705	707	768	845	1,229	1,540	1,815	2,080

(continued)

Appendix table 4-7. (Continued)

Industry	1960	1962	1964	1966	1968	1970	1972	1974	1976	1978	1979	1980	1981
	Millions of constant 1972 dollars[5]												
Total	$15,297	$16,236	$18,568	$20,255	$21,116	$19,756	$19,552	$19,889	$20,400	$22,142	$23,391	$24,914	$26,511
Food and kindred products	151	171	198	214	223	252	259	259	268	314	323	347	368
Textiles and apparel	55	40	44	66	70	63	61	60	62	59	62	64	63
Lumber, wood products, and furniture	15	14	16	16	24	57	64	73	81	85	85	83	85
Paper and allied products	82	92	106	152	174	195	189	206	237	257	272	277	290[1]
Chemicals and allied products	1,426	1,664	1,764	1,833	1,925	1,939	1,932	2,129	2,280	2,380	2,471	2,595	2,724
Industrial chemicals	969	1,045	1,189	1,196	1,189	1,127	1,031	1,129	1,152	1,195	1,201	1,230	1,306
Drugs and medicines	236	276	322	401	482	530	607	701	824	870	928	995	1,020[1]
Other chemicals	221	343	254	236	254	281	294	299	303	315	342	371	390[1]
Petroleum refining and extraction	431	439	540	483	529	563	468	540	580	705	772	869	980[1]
Rubber products	176	200	217	219	270	302	377	408	379	328	353	367	410[1]
Stone, clay, and glass products	128	136	150	152	172	183	183	189	199	215	218	227	240[1]
Primary metals	258	242	268	302	304	301	277	311	382	372	388	408	455
Ferrous metals and products[2]	149	137	159	181	164	163	146	157	193	209	229	248	290[1]
Nonferrous metals and products	109	105	109	121	139	138	130	154	189	164	158	160	170[1]
Fabricated metal products	211	207	203	201	222	226	253	272	271	255	278	308	326
Nonelectrical machinery	1,381	1,294	1,395	1,585	1,797	1,891	2,158	2,594	2,635	2,847	2,953	3,303	3,478
Office, computing, and accounting machines	([3])	([3])	([3])	([3])	([3])	([3])	1,456	1,827	1,815	1,917	1,967	2,218	2,310[1]
Electrical equipment	3,686	3,737	4,084	4,724	4,947	4,615	4,680	4,354	4,259	4,326	4,788	5,136	5,353
Radio and TV receiving equipment	([4])	([4])	([4])	61	67	77	48	44	39	86	150	311	310[1]
Electronic components	([3])	([3])	([3])	([3])	([3])	([3])	330	425	522	600	715	866	849
Communication equipment	1,927	2,253	2,572	2,930	3,053	2,847	2,583	2,106	1,897	1,994	2,224	2,253	2,423
Other electrical equipment	1,758	1,484	1,512	1,733	1,827	1,691	1,719	1,779	1,800	1,646	1,698	1,706	1,780[1]
Motor vehicles and other transportation equipment	1,287	1,415	1,624	1,751	1,816	1,740	2,010	2,152	2,170	2,666	2,856	2,864	2,602
Motor vehicles and motor vehicle equipment	([3])	([3])	([3])	([3])	([3])	([3])	1,954	2,076	2,099	2,579	2,759	2,774	2,521
Other transportation equipment	([3])	([3])	([3])	([3])	([3])	([3])	56	76	71	87	97	91	80[1]
Aircraft and missiles	5,115	5,724	6,978	7,199	6,984	5,707	4,950	4,586	4,790	5,010	4,920	5,149	5,985
Professional and scientific instruments	479	438	455	610	803	814	838	934	1,006	1,328	1,533	1,696	1,885
Scientific and mechanical measuring instruments	233	143	102	113	141	143	163	192	246	445	581	757	860[1]
Optical, surgical, photographic, and other instruments	246	295	353	496	660	670	675	742	761	883	952	939	1,020[1]
Other manufacturing industries	173	92	89	100	122	140	146	154	164	177	176	204	201
Nonmanufacturing industries	245	331	439	647	731	771	707	667	638	817	942	1,016	1,060[1]

[1]Estimated.
[2]Part of these expenditures was included in the nonferrous metals and products group in 1960–64.
[3]Data not tabulated at this level of detail prior to 1972.
[4]Included in the other electrical equipment group.
[5]GNP implicit deflators used to convert current dollars to constant 1972 dollars.

NOTE: Detail may not add to totals because of rounding.

SOURCES: 1960–1966: National Science Foundation, *Research and Development in Industry, 1971* (NSF 73-305), p. 28; 1968: National Science Foundation, unpublished data; 1970–1979: National Science Foundation, *Research and Development in Industry, 1980* (NSF 82-317), p. 11; 1980–81: National Science Foundation, preliminary data.

See figure 4-6.

Appendix table 4-8. Company and Federal funding of industrial R & D for selected industries: 1971 and 1981

Industry	Total 1971	Total 1981	Federal 1971	Federal 1981	Company[1] 1971	Company[1] 1981
	Millions of current dollars					
Total	$18,320	$51,830	$7,666	$16,468	$10,654	$35,362
Chemicals and allied products	1,832	5,325	184	383	1,648	4,942
Industrial chemicals	1,009	2,553	159	367	850	2,186
Drugs and medicines and other chemicals	823	2,770[2]	25	20[2]	798	2,756
Petroleum refining and extraction	505	1,920[2]	17	140[2]	488	1,777
Rubber products	289	800[2]	69	190[2]	221	616
Primary metals	272	889	6	182	266	707
Ferrous metals and products	144	560[2]	2	140[2]	142	414
Nonferrous metals and products	128	330[2]	4	40[2]	124	293
Fabricated metal products	242	638	11	80	230	558
Nonelectrical machinery	1,860	6,800	315	739	1,545	6,061
Electrical machinery	4,389	10,466	2,258	3,962	2,131	6,502
Communication equipment and electronic components	2,731	6,396	1,479	2,167	1,252	4,228
Motor vehicles and other transportation equipment	1,768	5,089[2]	309	704[2]	1,461	4,381
Aircraft and missiles	4,881	11,702	3,864	8,501	1,017	3,201
Professional and scientific instruments	746	3,685	164	638	583	3,047
Scientific and mechanical measuring instruments	133	1,680[2]	14	400[2]	120	1,285
Optical, surgical, photographic, and other instruments	612	2,000[2]	150	240[2]	463	1,762
All other manufacturing industries	2,889	8,325[2]	395	963[2]	2,494	7,368
Nonmanufacturing industries	704	2,080[2]	452	880[2]	252	1,199
	Millions of constant 1972 dollars[3]					
Total	$19,081	$26,511	$7,984	$8,423	$11,097	$18,087
Chemicals and allied products	1,908	2,724	192	196	1,716	2,528
Industrial chemicals	1,051	1,306	166	188	885	1,118
Drugs and medicines and other chemicals	857	1,410[2]	26	10[2]	831	1,410
Petroleum refining and extraction	526	980[2]	18	70[2]	508	909
Rubber products	301	410[2]	72	97[2]	230	315
Primary metals	283	455	6	93	277	362
Ferrous metals and products	150	290[2]	2	70[2]	148	212
Nonferrous metals and products	133	170[2]	4	20[2]	129	150
Fabricated metal products	252	326	11	41	240	285
Nonelectrical machinery	1,937	3,478	328	378	1,609	3,100
Electrical equipment	4,571	5,353	2,352	2,026	2,220	3,326
Communication equipment and electronic components	2,844	3,272	1,540	1,108	1,304	2,163
Motor vehicles and other transportation equipment	1,841	2,602[2]	322	360[2]	1,522	2,241
Aircraft and missiles	5,084	5,985	4,025	4,348	1,059	1,637
Professional and scientific instruments	777	1,885	171	326	607	1,558
Scientific and mechanical measuring instruments	139	860[2]	15	210[2]	125	657
Optical, surgical, photographic, and other instruments	637	1,020[2]	156	120[2]	482	901
All other manufacturing industries	3,009	4,260[2]	411	490[2]	2,598	3,769
Nonmanufacturing industries	733	1,060[2]	471	450[2]	262	613

[1]Includes all sources other than the Federal Government.
[2]Estimated.
[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Research and Development in Industry, 1980* (NSF 82-317), pp. 11, 14, and 17, and National Science Foundation, preliminary data.

See table 4-2 in text.

Appendix table 4-9. Domestic R & D funding by U.S. corporations and foreign funding by U.S. corporations and their foreign affiliates for selected industries: 1974–81

[Millions of dollars]

Industry	1974[1]			1975			1976			1977		
	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total
Total	14,667	1,300	15,967	15,582	1,454	17,036	17,436	1,659	19,095	19,340	1,877	21,217
Food and kindred products	297	27	324	NA	23	NA	NA	29	NA	NA	32	NA
Chemicals and allied products	2,236	208	2,444	2,490	269	2,759	2,751	312	3,063	2,907	332	3,239
Industrial chemicals	1,105 }	82	NA	1,173 }	85	NA	1,275 }	108	NA	1,387 }	133	NA
Other chemicals	NA }		NA	NA }		NA	NA }		NA	NA }		NA
Drugs and medicines	NA	126	NA	NA	184	NA	NA	204	NA	NA	199	NA
Petroleum refining and related industries	603	NA	NA	NA	NA	NA	715	NA	NA	842	NA	NA
Stone, clay, and glass products	203	7	210	NA	7	NA	NA	NA	NA	NA	NA	NA
Primary metals	350	3	353	422	9	431	481	12	493	494	9	503
Fabricated metal products	299	NA	NA	297	NA	NA	322	22	344	342	24	366
Nonelectrical machinery	2,473	258	2,731	2,687	331	3,018	2,955	352	3,307	3,403	411	3,814
Electrical equipment	2,704	238	2,942	2,798	245	3,043	3,081	278	3,359	3,238	300	3,538
Electronic components and other electrical equipment	NA	NA	NA	NA	NA	NA	1,611[2]	15	1,626[2]	1,574[2]	18	1,592[2]
Radio and TV receiving equipment, communication equipment	NA	NA	NA	NA	NA	NA	1,470	263[2]	1,733[2]	1,664	282[2]	1,946[2]
Motor vehicles and other transportation equipment	2,141	364	2,505	2,065	373	2,438	NA	423	2,818	NA	514	3,401
Aircraft and missiles	1,278	42	1,320	1,285	39	1,324	1,418	41	1,459	1,547	44	1,591
Professional and scientific instruments	908	39	947	1,001	49	1,050	1,168	49	1,217	1,350	51	1,401
Nonmanufacturing industries	305	3	308	425	4	429	471	4	475	541	9	550

Industry	1978			1979			1980			1981		
	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total
Total	22,115	2,209	24,324	25,708	2,754	28,462	30,476	3,165	33,641	35,362	3,157	38,519
Food and kindred products	NA	43	NA	NA	51	NA	NA	54	NA	713	66	779
Chemicals and allied products	3,250	395	3,645	3,692	500	4,192	4,264	603	4,867	4,942	651	5,593
Industrial chemicals	1,473 }	151	NA	1,617 }	199	NA	1,856 }	245	2,754	2,186	204	2,390
Other chemicals	NA }		NA	NA }		NA	653 }			759	71	830
Drugs and medicines	NA	244	NA	NA	301	NA	1,756	357	2,113	1,997	376	2,373
Petroleum refining and related industries	939	NA	NA	1,109	NA	NA	1,401	141	1,542	1,777	192	1,969
Stone, clay, and glass products	NA	NA	NA	NA	NA	NA	363	21	384	411	15	426
Primary metals	497	9	506	539	11[2]	539	594	11	605	707	9	716
Fabricated metal products	348	29	377	414	32	446	501	33[2]	534[2]	558	26[2]	584[2]
Nonelectrical machinery	3,901	460	4,361	4,490	534	5,024	5,254	599	5,853	6,061	585	6,646
Electrical equipment	3,791	352	4,143	4,515	445	5,960	5,431	451	5,882	6,502	455	6,957
Electronic components and other electrical equipment	1,926[2]	26	1,952[2]	2,279[2]	36	2,315[2]	2,718	40	2,758	3,192	59	3,251
Radio and TV receiving equipment, communication equipment	1,865	326[2]	2,191[2]	2,236	409[2]	2,645[2]	2,713	411[2]	3,124[2]	3,310	396[2]	3,706[2]
Motor vehicles and other transportation equipment	NA	NA	NA	NA	NA	NA	4,388	934[2]	5,322[2]	4,381	791[2]	5,172[2]
Aircraft and missiles	1,823	NA	NA	2,201	NA	NA	2,570	86[2]	2,656[2]	3,201	102[2]	3,303[2]
Professional and scientific instruments	1,668	61	1,729	2,012	76	2,088	2,456	86	2,542	3,047	101	3,148
Nonmanufacturing industries	702	12	614	859	5	864	1,037	7	1,044	1,199	12	1,211

[1]Based on data obtained from only the top 200 U.S. R & D-performing companies.
[2]Estimated.

NA = Not available.

SOURCES: National Science Foundation, *Research and Development in Industry: 1980, Detailed Statistical Tables* (NSF 82-317), pp. 14, 16, and National Science Foundation, unpublished tabulations.

See figure 4-7.

Appendix table 4-10. Percent of transferred technologies that are new processes, process improvements, new products, and product improvements, by industry and size of firm: 1979

Industry or size of firm	New processes	Process improvements	New products	Product improvements	Total[2]
Total	5	4	72	19	100
			By industry		
Chemical	2	19	76	3	100
Machinery	—	—	81	19	100
Electrical equipment	7	7	50	36	100
Instruments	—	2	24	74	100
Other	11	—	89	—	100
			By firm size		
Larger firms[1]	2	3	75	19	100
Smaller firms[1]	19	11	51	18	100

[1]Larger firms are those with worldwide sales exceeding $2 billion in 1977; smaller firms are the others.
[2]Detail may not add to totals because of rounding.

NOTE: These data are based on a sample of overseas laboratories accounting for about 10 percent of all overseas R & D of American companies. Obviously, they contain sampling uncertainties.

SOURCE: Edwin Mansfield and Anthony Romeo, "'Reverse' Transfers of Technology from Overseas Subsidiaries to American Firms," University of Pennsylvania, 1983.

Science Indicators—1982

Appendix table 4-11. U.S. patents granted, by nationality of inventor: 1960–82

Year	By date of application			By date of grant		
	All U.S. patents	To U.S. inventors	To foreign inventors	All U.S. patents	To U.S. inventors	To foreign inventors
1960	NA	NA	NA	47,170	39,472	7,698
1961	NA	NA	NA	48,368	40,154	8,214
1962	NA	NA	NA	55,691	45,579	10,112
1963	NA	NA	NA	45,679	37,174	8,505
1964	NA	NA	NA	47,375	38,411	8,964
1965	54,840	42,205	12,635	62,857	50,332	12,525
1966	59,661	45,004	14,657	68,405	54,634	13,771
1967	60,007	44,153	15,854	65,652	51,274	14,378
1968	62,965	45,334	17,631	59,103	45,783	13,320
1969	65,846	46,388	19,458	67,559	50,395	17,164
1970	65,923	45,836	20,087	64,429	47,077	17,352
1971	66,328	45,556	20,772	78,362	56,011	22,351
1972	63,333	42,408	20,925	74,763	51,496	23,267
1973	66,256	42,713	23,543	74,142	51,503	22,639
1974	66,324	41,779	24,545	76,278	50,649	25,629
1975	65,717	42,125	23,592	72,002	46,713	25,289
1976	65,469	41,411	24,058	70,227	44,277	25,750
1977	65,041	40,223	24,818	65,269	41,484	23,785
1978[2]	65,100	39,700	25,400	66,100	41,252	24,848
1979[2]	64,800	39,100	25,700	48,852[1]	30,079[1]	18,773[1]
1980[2]	67,300	40,100	27,200	61,819	37,356	24,463
1981[2]	69,000	40,600	28,400	65,770	39,224	26,546
1982[2]	70,700	40,900	29,800	57,889	33,896	23,993

NA = Not available.

[1]Patent counts for 1979 are spuriously low because of a lack of funds in the Patent Office for printing and issuing patents.

[2]Data by date of application are estimated for these years.

SOURCES: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office (OTAF), *Special Report: A profile of U.S. Patent Activity*, 1978; OTAF, *Indicators of Patent Output of U.S. Industry (1963–79)*, June 1980; OTAF, *Indicators of Patent Output of U.S. Industry (1963–81)*, June 1982; and OTAF, unpublished data.

See figure 4-8.

Science Indicators—1982

Appendix table 4-12. U.S. patents granted to U.S. inventors, by type of owner: 1961–82

Year	By date of application					By date of grant				
	All patents	U.S. corp.	U.S. Gov't.	U.S. individual[1]	Foreign[2]	All patents	U.S. corp.	U.S. Gov't.	U.S. individual[1]	Foreign[2]
1961	NA	NA	NA	NA	NA	40,154	27,383	1,460	11,233	79
1962	NA	NA	NA	NA	NA	45,579	31,377	1,276	12,817	109
1963	NA	NA	NA	NA	NA	37,174	25,722	1,017	10,358	77
1964	NA	NA	NA	NA	NA	38,411	26,808	1,174	10,336	93
1965	42,205	30,155	1,426	10,475	149	50,332	35,698	1,522	13,032	80
1966	45,004	32,887	1,481	10,412	224	54,634	39,891	1,512	13,050	181
1967	44,153	32,040	1,562	10,313	238	51,274	36,745	1,726	12,634	169
1968	45,334	32,980	1,714	10,362	278	45,783	33,351	1,458	10,768	206
1969	46,388	33,664	1,813	10,601	310	50,395	37,073	1,806	11,299	217
1970	45,836	33,040	1,621	10,868	307	47,077	34,948	1,761	10,096	272
1971	45,556	32,586	1,589	11,104	277	56,011	40,850	2,136	12,597	428
1972	42,408	30,532	1,514	10,136	226	51,496	37,855	1,764	11,555	322
1973	42,713	30,505	1,381	10,598	229	51,503	36,812	2,078	12,346	267
1974	41,779	30,071	1,568	9,882	258	50,649	36,073	1,727	12,549	300
1975	42,125	30,230	1,482	10,222	191	46,713	33,395	1,882	11,181	255
1976	41,411	28,965	1,329	10,893	224	44,277	32,136	1,807	10,081	253
1977	40,223	28,075	1,156	10,736	256	41,484	29,546	1,480	10,248	210
1978[4]	39,700	27,800	1,200	10,500	300	41,252	29,380	1,228	10,400	244
1979[4]	39,100	27,300	1,200	10,300	300	30,079[3]	21,125[3]	951[3]	7,809[3]	194[3]
1980[4]	40,100	28,100	1,200	10,600	300	37,356	25,910	1,226	9,940	280
1981[4]	40,600	28,400	1,200	10,700	300	39,224	27,592	1,112	10,243	277
1982[4]	40,900	28,700	1,100	10,800	300	33,896	24,045	1,000	8,540	311

[1]Includes unassigned patents.
[2]Comprises patents assigned to foreign corporations, governments, and individuals.
[3]Patent counts for 1979 are spuriously low because of a lack of funds in the Patent Office for printing and issuing patents.
[4]Data by date of application are estimated for these years.

NA = Not available.

SOURCES: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office (OTAF), *Special Report: A Profile of U.S. Patent Activity*, 1978; OTAF, *Indicators of Patent Output of U.S. Industry, iv (1963–79)*, June 1980; OTAF, *Indicators of the Patent Output of U.S. Industry (1963–81)*, June 1982; OTAF, unpublished data.

See figure 4-9.

Appendix table 4-13. Number of U.S. patents due to U.S. inventors, by product field, for patents granted in 1981

Product field	1981 patents	Average percent change per year, (1971–1981)
All product fields	39,224	−4.6
Food and kindred products	542	−5.0
Textile mill products	432	−5.1
Chemicals and allied products	6,919	−1.8
Chemicals, except drugs and medicines	6,762	−1.9
Basic industrial inorganic and organic chemicals	3,312	−3.6
Industrial inorganic chemicals	970	− .9
Industrial organic chemicals	2,631	−4.3
Plastics materials and synthetic resins	1,726	−1.0
Agricultural chemicals	1,049	6.1
All other chemicals	767	−3.6
Soap, detergents, and cleaning preparations, perfumes, cosmetics, and other toilet preparations	291	−1.1
Paints, varnishes, lacquers, enamels, and allied products	55	.1
Miscellaneous chemical products	451	−5.5
Drugs and medicines	1,308	5.3
Petroleum and natural gas extraction and petroleum refining	792	−1.2
Rubber and miscellaneous plastics products	2,354	−3.4
Stone, clay, glass, and concrete products	1,109	−4.5
Primary metals	431	−5.8
Primary ferrous products	320	−5.6
Primary and secondary nonferrous products	243	−6.2
Fabricated metal products	5,400	−4.3
Nonelectrical machinery	11,066	−5.6
Engines and turbines	1,017	−1.1
Farm and garden machinery and equipment	1,243	−4.7
Construction, mining, and material handling machinery and equipment	1,875	−6.0
Metal working machinery and equipment	874	−8.5
Office, computing, and accounting machines	1,425	−5.2
Other nonelectrical machinery	6,528	−5.8
Special industry machinery, except metal working machinery	2,451	−6.4
General industrial machinery and equipment	3,389	−5.9
Refrigeration and service industry machinery	892	−5.6
Miscellaneous nonelectrical machinery	651	−5.3
Electrical and electronic machinery, equipment, and supplies	7,509	−5.9
Electrical equipment, except communication equipment	3,993	−6.0
Electrical transmission and distribution equipment	1,256	−7.2
Electrical industrial apparatus	1,044	−7.0
Other electrical machinery, equipment, and supplies	2,096	−4.8
Household appliances	666	−5.4
Electrical lighting and wiring equipment	497	−5.8
Miscellaneous electrical machinery, equipment, and supplies	920	−3.9
Communication equipment and electronic components	4,196	−6.0
Radio and television receiving equipment, except communication types	751	−6.0
Electronic components and accessories and communication equipment	4,116	−6.1
Transportation equipment	2,416	−4.6
Motor vehicles and other transportation equipment	2,245	−4.6
Motor vehicles and motor vehicle equipment	1,421	−2.9
Guided missiles and space vehicles and parts	177	−4.5
Other transportation equipment	695	−7.4
Ship and boat building and repairing	225	−6.9
Railroad equipment	332	−8.1
Motorcycles, bicycles, and parts	62	−5.6
Miscellaneous transportation equipment	392	−6.0
Ordnance, except missiles	225	−7.4
Aircraft and parts	849	−1.4
Professional and scientific instruments	5,404	−4.0

SOURCE: Calculated from Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of Patent Output of U.S. Industry (1963–1981)*. "All product fields" from appendix table 4-12.

See table 4-4 in text.

Appendix table 4-14. Initial public offerings of stock in high-technology companies: 1972–81

Year	Number of issues	Total amount (millions of dollars)
1972	91	$189.2
1973	23	50.1
1974	3	4.7
1975	0	0.0
1976	7	42.3
1977	10	65.2
1978	21	76.3
1979	16	82.1
1980	60	431.3
1981	170[1]	NA

[1]The 1981 datum is from *Going Public: The IPO Reporter*, vol. 6 (Jan. 14, 1982), p. 325, and is calculated on a slightly different basis from the other data. The *IPO Reporter* estimate for the number of issues in 1980 is 51.

NA = Not available.

SOURCE: U.S. Securities and Exchange Commission and U.S. Small Business Administration, *The Role of Regional Broker-Dealers in the Capital Formation Process: Underwriting, Market-Making and Securities Research Activities*, Phase II Report (August 1981), p. 21.

See figure 4-10.

Science Indicators—1982

Appendix table 4-15. Capital commitments and disbursements to new ventures: 1975–82

Year	Millions of dollars		
	Total disbursements by venture capital industry	Straight equity acquisition disbursements[1]	Private capital committed to venture capital firms
1975	250	136	10
1976	300	185	50
1977	400	207	39
1978	550	332	570
1979	1,000	665	319
1980	1,100	799	900
1981	1,400	NA	1,300
1982 (prel.) ...	1,700	NA	1,700

[1]Excludes SBIC straight debt lending and leveraged buyout financing, but includes mixed equity-debt financings.

SOURCE: Venture Economics, *Venture Capital Investments and Small, High-Technology Companies: A Measure of the High-Technology, Small Business Sector*, report to the National Science Foundation (February 1982), p. 11; and Venture Economics, unpublished data.

Science Indicators—1982

Appendix table 4-16. Venture capital investments in small high-technology companies: 1975 and 1980

[Millions of dollars]

	Year	
	1975	1980
Early- and later-stage funding	$136	$799
High-technology component	72	425
Early-stage funding	50	343
High-technology component	35	192
Later-stage funding	86	456
High-technology component	37	233

SOURCES: Appendix tables 4-15 and 4-17 and Venture Economics, unpublished tabulations.

See figure 4-11.

Science Indicators—1982

Appendix table 4-17. Venture capital investments in small high-technology companies, by product field: 1975 and 1980.

Product field	Percent of all early-stage funding		Percent of all early- and later-stage funding	
	1975	1980	1975	1980
All high-technology product fields	69.3	56.1	52.7	53.2
Industrial chemicals	—	—	3.9	.1
Drugs and medicines	.6	7.1	.2	3.1
Agricultural chemicals	2.6	—	.9	—
Plastic materials and synthetics	—	—	.9	.3
Office, computing, and accounting machines	54.6	28.6	28.6	26.6
Communication equipment and electronic components	2.5	13.3	8.9	14.5
Engines and turbines	—	2.1	.9	.9
Aircraft and parts	—	.2	—	.1
Professional, scientific, and measuring instruments	5.7	2.1	3.7	3.6
Optical and medical instruments, photos, watches	3.3	2.9	6.0	3.6

SOURCES: Venture Economics, *Venture Capital Investment and Small, High-Technology Companies: A Measure of the High-Technology, Small Business Sector,* Report to the National Science Foundation (February 1982), p. 20, and Venture Economics, unpublished data.

Science Indicators—1982

Appendix table 4-18. Share of corporate patenting accounted for by small business, by product field: 1980

Product field	Percent of all corporate patents
Fields with high shares:	
Refrigeration and service industry machinery	34
Farm and garden machinery and equipment	32
Construction, mining, and material handling machinery and equipment	32
Fabricated metal products	29
Other nonelectrical machinery	26
Fields with low shares:	
Petroleum and natural gas extraction, and petroleum refining	10
Industrial inorganic chemicals	7
Drugs and medicines	6
Plastics materials and synthetic resins	5
Agricultural chemicals	5
Industrial organic chemicals	2
	Drop in Percent Share
Fields with significant decreases, 1974 to 1980:	
Miscellaneous nonelectrical machinery	22
Farm and garden machinery and equipment	15
Construction, mining, and material handling machinery and equipment	13
Electrical transmission and distribution equipment	12
Office, computing, and accounting machines	9
General industrial machinery and equipment	8
Other nonelectrical equipment	6

NOTE: Percentages are approximate because of small samples in some fields. Similarly, some fields are not shown because the sample contained too few patents in them to produce significant results.

SOURCE: U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, *Small Business Patenting,* July 1982.

Science Indicators—1982

Appendix table 4-19. Industry's expenditures for R & D in universities and colleges: 1960–83

[Millions of dollars]

Year	Current dollars	Constant 1972 dollars[1]
1960	40	58
1961	40	58
1962	40	57
1963	41	57
1964	40	55
1965	41	55
1966	42	55
1967	48	61
1968	55	67
1969	60	69
1970	61	67
1971	70	73
1972	74	74
1973	84	79
1974	96	83
1975	113	90
1976	123	93
1977	139	99
1978	170	113
1979	193	118
1980	235	132
1981 (preliminary)	285	146
1982 (estimate)	320	154
1983 (estimate)	360	165

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319), p. 24, and National Science Foundation, unpublished tabulations.

See figure 4-12.

Science Indicators—1982

Appendix table 4-20. Doctoral scientists and engineers in business and industry reporting teaching as a secondary work activity, by field: 1979 and 1981

Field	1979	1981
All S/E fields	2,450	3,330
All scientists	1,970	2,420
Physical scientists	290	170
Chemists	280	140
Physicists and astronomers	10	30
Mathematical scientists	40	110
Mathematicians	40	80
Statisticians	([1])	40
Computer specialists	60	190
Environmental scientists	20	110
Earth scientists	20	110
Oceanographers	([1])	([1])
Atmospheric scientists	([1])	([1])
Life scientists	300	320
Biological scientists	60	70
Agricultural scientists	10	20
Medical scientists	230	230
Psychologists	980	1,140
Social scientists	280	380
Economists	120	220
Sociologists and anthropologists	20	([1])
Other social scientists	150	150
All engineers	480	900

[1]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 4-13.

Science Indicators—1982

Appendix table 4-21. Flow of doctoral scientists and engineers between academia and industry by field: 1979 to 1981

Field	Employed in business and industry in both 1979 and 1981	Moving from academia in 1979 to industry in 1981	Employed in academia in both 1979 and 1981	Moving from industry in 1979 to academia in 1981
Total, all fields	61,070	4,580	129,070	1,020
All scientists	41,240	3,750	116,020	800
Physical scientists	19,230	880	20,110	300
Chemists	15,910	540	10,940	240
Physicists and astronomers	3,320	340	9,180	50
Mathematical scientists	1,080	350	9,400	60
Mathematicians	820	280	7,860	50
Statisticians	260	70	1,530	10
Computer specialists	2,490	120	1,700	20
Environmental scientists	3,130	190	4,380	20
Earth scientists	2,800	160	3,380	20
Oceanographers	130	20	520	([1])
Atmospheric scientists	200	10	480	([1])
Life scientists	8,330	1,190	39,840	230
Biological scientists	3,260	630	25,500	100
Agricultural scientists	2,290	170	6,280	120
Medical scientists	2,780	390	8,050	20
Psychologists	4,910	420	13,070	80
Social scientists	2,060	600	27,520	90
Economists	1,120	120	6,120	10
Sociologists and anthropologists	170	160	7,030	30
Other social scientists	770	330	14,360	60
All engineers	19,840	830	13,050	220

[1]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 4-14.

Appendix table 4-22. Index[1] of cooperative research between industry and selected other sectors, by field: 1973, 1977, and 1980

Field[2]	Industry with universities			Industry with other industry[3]			Industry with Federal Government		
	1973	1977	1980	1973	1977	1980	1973	1977	1980
	Percent of industry articles with other-sector participation								
All fields	13	15	19	5	5	6	3	4	4
Clinical medicine	21	23	30	5	7	8	7	8	8
Biomedicine	19	26	32	3	3	5	8	9	8
Biology	19	28	35	3	4	4	3	6	12
Chemistry	9	10	13	4	3	3	1	2	1
Physics	13	15	18	4	3	4	2	3	4
Earth and space sciences	28	27	31	3	3	5	8	9	13
Engineering and technology	9	10	13	6	7	8	2	2	3
Mathematics	29	40	39	3	2	3	—	2	2
	Number of industry articles with other-sector participation								
All fields	1,566	1,595	2,017	575	541	628	360	392	465
Clinical medicine	329	331	467	78	93	116	119	109	124
Biomedicine	117	148	175	20	19	29	52	49	42
Biology	86	113	116	14	18	13	14	23	39
Chemistry	185	158	215	78	47	54	27	28	25
Physics	246	290	423	68	60	99	33	60	88
Earth and space sciences	102	95	119	11	9	18	27	32	50
Engineering and technology	463	418	459	304	293	296	88	89	95
Mathematics	38	42	43	2	2	3	—	2	2
	Total number of industry articles[4]								
All fields	12,180	10,544	10,422	12,180	10,544	10,422	12,180	10,544	10,422
Clinical medicine	1,600	1,413	1,533	1,600	1,413	1,533	1,600	1,413	1,533
Biomedicine	618	567	548	618	567	548	618	567	548
Biology	446	407	332	446	407	332	446	407	332
Chemistry	1,983	1,539	1,708	1,983	1,539	1,708	1,983	1,539	1,708
Physics	1,911	1,932	2,302	1,911	1,932	2,302	1,911	1,932	2,302
Earth and space sciences	358	348	381	358	348	381	358	348	381
Engineering and technology	5,130	4,231	3,507	5,130	4,231	3,507	5,130	4,231	3,507
Mathematics	134	107	111	134	107	111	134	107	111

[1]Obtained by dividing the number of articles which were written jointly by authors from industry and the sectors shown, by the total number of articles which had industry participation. The index is based on the articles, notes, and reviews from over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See Appendix table 1-13 for the subfields included in these fields.
[3]In this case, the "other sector" is another industrial company. Cooperative research between affiliated companies is included.
[4]All articles with at least one industry author.

NOTE: Federally funded research and development centers which are administered by these sectors are excluded from these data.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 4-23. Relative citation ratios[1] between industry and university articles published in 1973–78

Field[2]	1973	1974	1975	1976	1977	1978
	Citing from university to industry articles					
All fields	0.37	0.36	0.36	0.37	0.37	0.37
Clinical medicine	.56	.48	.46	.49	.48	.41
Biomedicine	.64	.64	.71	.64	.66	.56
Biology	.55	.43	.62	.71	.50	.54
Chemistry	.39	.40	.38	.42	.42	.38
Physics	.71	.67	.70	.68	.67	.87
Earth and space sciences	.53	.49	.35	.44	.42	.42
Engineering and technology	.46	.47	.45	.46	.45	.43
Mathematics	.77	.70	1.31	.72	.85	.69
	Citing from industry to university articles					
All fields	0.62	0.61	0.59	0.59	0.57	0.54
Clinical medicine	.72	.74	.73	.74	.70	.76
Biomedicine	.73	.71	.70	.69	.72	.70
Biology	.80	.79	.70	.69	.62	.61
Chemistry	.58	.59	.59	.59	.58	.60
Physics	.47	.48	.44	.48	.44	.43
Earth and space sciences	.76	.78	.81	.74	.79	.80
Engineering and technology	.58	.53	.57	57	.54	.53
Mathematics	.69	.69	.65	.62	.85	.77

[1]A citation ratio of 1.00 would mean that the cited sector received a share of citations in that field equal to its share of publications by U.S. authors in that field. Because all sectors tend to cite their own research more than others', these ratios are less than 1.00. However, their relative magnitudes can be compared.

[2]See appendix table 1-13 for the subfields included in these fields.

NOTE: These data are based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* corporate tapes of the Institute for Scientific Information.

See table 4-5 in text.

Science Indicators—1982

Appendix table 5-1. Number of institutions of higher education and number awarding science and engineering degrees by highest degree awarded: 1960–81

Year	Total higher education institutions	Four-year institutions: 4-year institution total	Granting S/E degrees (highest degree): Total	Bachelors and first professional	Master's	Doctor's	Not granting S/E degrees	Two-year institutions
1960	2,021	1,446	1,056	735	180	141	390	575
1961	2,034	1,441	1,090	748	189	153	351	593
1962	2,050	1,464	1,112	745	212	155	352	586
1963	2,106	1,476	1,125	754	209	162	351	630
1964	2,146	1,509	1,147	757	218	172	362	637
1965	2,189	1,532	1,165	754	233	178	367	657
1966	2,247	1,565	1,178	745	246	187	387	682
1967	2,347	1,592	1,217	752	271	194	375	755
1968	2,392	1,603	1,223	746	281	196	380	789
1969	2,503	1,636	1,254	756	292	206	382	867
1970	2,544	1,654	1,274	762	292	220	380	890
1971	2,573	1,681	1,276	760	287	229	405	892
1972	2,626	1,689	1,362	795	319	248	327	937
1973	2,689	1,772	1,396	815	318	263	376	967
1974	2,744	1,737	1,400	802	327	271	337	1,007
1975	3,012	1,871	1,420	813	340	267	451	1,141
1976	3,026	1,898	NA	NA	NA	NA	NA	1,128
1977	3,046	1,913	NA	NA	NA	NA	NA	1,133
1978	3,095	1,938	1,445	804	359	282	493	1,157
1979	3,134	1,941	NA	NA	NA	NA	NA	1,193
1980	3,152	1,957	NA	NA	NA	NA	NA	1,195
1981	3,231	1,957	1,447	793	361	293	510	1,274

NA = Not available.

SOURCES: National Science Foundation, *Databook* (series), February 1969 and January 1975; National Center for Education Statistics, *Digest of Education Statistics 1982,* and unpublished data.

See figure 5-1.

Science Indicators—1982

Appendix table 5-2. Science and engineering degrees by level: 1960–81

Year	Total S/E degrees	Bachelor's	Master's	Doctor's
1960	147,005	120,937	20,012	6,056
1961	150,977	121,660	22,786	6,531
1962	159,864	127,469	25,146	7,249
1963	171,386	135,964	27,367	8,055
1964	192,657	153,361	30,271	9,025
1965	209,023	164,936	33,835	10,252
1966	222,852	173,471	38,083	11,298
1967	242,408	187,849	41,800	12,759
1968	271,727	212,174	45,425	14,128
1969	308,783	244,519	48,425	15,839
1970	331,079	264,122	49,318	17,639
1971	340,266	271,176	50,624	18,466
1972	353,207	281,228	53,567	18,412
1973	368,223	295,391	54,234	18,598
1974	377,102	305,062	54,175	17,865
1975	366,556	294,920	53,852	17,784
1976	364,209	292,174	54,747	17,288
1977	362,211	288,543	56,731	16,937
1978	360,600	288,167	56,237	16,196
1979	359,444	288,625	54,456	16,363
1980	362,857	291,983	54,391	16,483
1981	366,651	294,867	54,811	16,973

SOURCE: National Science Foundation, *Science and Engineering Degrees, 1950–1980* (NSF 82-307), and unpublished data.

See figure 5-1.

Science Indicators—1982

Appendix table 5-3. Fifteen leading countries of origin of foreign students in the U.S. by number of students and academic level: 1981/82

Country	Number of students: Total	Number of students: Graduate	Graduate enrollment as percent of total
Iran	35,860	8,248	23
Taiwan	20,520	16,416	80
Nigeria	19,560	5,281	27
Canada	14,950	4,784	32
Japan	14,020	4,066	29
Venezuela	13,960	2,652	19
India	11,250	8,550	76
Saudi Arabia	10,220	2,146	21
Malaysia	9,420	1,884	20
Hong Kong	8,990	2,877	32
Korea	8,070	5,810	72
Mexico	7,890	2,919	37
Lebanon	6,800	1,088	16
Thailand	6,730	3,702	55
Jordan	6,180	927	15

[1] Estimates of graduate enrollments are based on the biennial survey "Step 3 Individual Data Survey"; while estimates of the total number of foreign students enrolled in U.S. higher education institutions are derived from the annual "Step 2 Institutional Data Survey", both of which are conducted by the Institute of International Education.

SOURCE: Institute of International Education, unpublished data.

Science Indicators—1982

Appendix table 5-4. R&D expenditures in science and engineering at universities and colleges, by highest degree granted and rank[1]: 1975 and 1981

(Dollars in millions)

Institutional ranking[1]	All institutions: Dollars	All institutions: Cumulative percent	Doctorate-granting: Dollars	Doctorate-granting: Cumulative percent	Master's granting: Dollars	Master's granting: Cumulative percent	All other[2]: Dollars	All other[2]: Cumulative percent
				1975				
First 10	$ 731.5	21.6	$ 731.5	22.0	$17.2	35.2	$14.1	54.9
First 20	1,225.3	36.1	1,225.3	36.9	25.8	52.8	18.6	72.4
First 30	1,587.1	46.8	1,587.1	47.8	32.2	65.8	21.5	83.7
First 40	1,869.1	55.1	1,869.1	56.3	37.0	75.7	23.0	89.5
First 50	2,101.8	61.9	2,101.8	63.3	39.8	81.4	24.1	93.8
First 60	2,288.9	67.5	2,288.9	69.0	—	—	—	—
First 70	2,452.3	72.3	2,452.3	73.9	—	—	—	—
First 80	2,598.2	76.6	2,598.2	78.3	—	—	—	—
First 90	2,713.8	80.0	2,713.8	81.8	—	—	—	—
First 100	2,811.8	82.9	2,811.8	84.7	—	—	—	—
Total	3,393.1	100.0	3,318.6	100.0	48.9	100.0	25.7	100.0
				1981				
First 10	$1,496.0	22.0	$1,496.0	22.4	$27.2	31.4	$14.9	59.8
First 20	2,414.9	35.6	2,414.9	36.1	43.2	49.9	20.5	82.3
First 30	3,135.3	46.2	3,135.3	47.2	55.0	63.5	23.0	92.4
First 40	3,702.0	54.5	3,702.0	55.4	62.8	72.5	24.3	97.6
First 50	4,152.6	61.1	4,152.6	62.2	68.7	79.3	24.8	99.6
First 60	4,552.5	67.0	4,552.5	68.1	—	—	—	—
First 70	4,894.8	72.1	4,894.8	73.3	—	—	—	—
First 80	5,198.7	76.5	5,198.7	77.8	—	—	—	—
First 90	5,433.9	80.0	5,433.9	81.3	—	—	—	—
First 100	5,631.6	82.9	5,631.6	84.3	—	—	—	—
Total	6,793.3	100.0	6,681.8	100.0	86.6	100.0	24.9	100.0

[1] Ranked by total amount of R&D expenditures.

[2] Includes those with only S/E bachelor's degrees and those with no science degrees at any level.

NOTE: Detail may not add to totals due to rounding.

SOURCES: National Science Foundation, *Expenditures for Scientific Activities at Universities and Colleges, Fiscal Year 1975* (NSF 76-316), pp. 21–23, and *Academic Science/Engineering, R&D Funds, Fiscal Year 1981* (NSF 83-308), pp. 47-50.

See table 5-2 in text.

Science Indicators—1982

Appendix table 5-5. Relative concentration of R&D expenditures at leading doctorate-granting institutions by rank: total and Federal sources: 1975–81

(Percent)

Source and ranking	1975	1976	1977	1978	1979	1980	1981
All sources:							
First 10	22.0	21.1	20.7	20.2	23.0	22.6	22.4
First 20	36.9	36.3	35.7	34.5	36.4	36.4	36.1
First 100	84.7	85.2	84.9	83.9	84.4	84.4	84.3
Federal support only:							
First 10	24.1	23.5	23.5	23.1	27.1	26.5	26.2
First 20	40.6	40.2	39.7	37.9	41.0	40.9	40.4
First 100	84.7	86.3	85.9	84.1	85.1	85.1	85.1

SOURCE: National Science Foundation, *Academic Science/Engineering: R&D Funds, FY 1981* (NSF 83-308), and earlier years.

See table 5-3 in text.

Science Indicators—1982

Appendix table 5-6. Relative distribution of R&D expenditures in doctorate-granting institutions by source of support and institutional rank: 1975 and 1981

(Dollars in millions)

Institutional rank	Total	Federal Government	State/local government	Industry	Institutional funds	Other sources
			1975			
Total	$3,318.6	$2,233.0	$345.2	$108.7	$382.7	$249.0
First 10	731.5	537.4	38.2	14.2	79.3	62.4
First 20	1,225.3	907.3	63.3	23.5	127.5	103.7
First 100	2,811.8	1,891.4	304.4	81.8	326.6	207.6
			1981			
Total	$6,681.8	$4,476.2	$528.5	$279.0	$959.4	$438.7
First 10	1,496.0	1,173.8	73.4	50.1	101.5	97.1
First 20	2,414.9	1,810.0	122.9	66.4	245.3	170.4
First 100	5,631.6	3,805.4	452.2	216.6	798.2	359.3

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Expenditures for Scientific Activities at Universities and Colleges, Fiscal Year 1975* (NSF 76-316), pp. 20 and 21, and *Academic Science/Engineering: R&D Funds, Fiscal Year 1981* (NSF 83-308), pp. 47–48.

Appendix table 5-7. Relative distribution of full-time S/E graduate enrollments and postdoctoral appointments in doctorate-granting institutions by institutional rank[1]: Fall 1976 and Fall 1979

Student characteristic and institutional rank	1976	1979
	Enrollment	
Total full-time students		
Top 20[1]	55,067	60,314
All doctorate-granting	214,090	223,414
	By gender	
Men		
Top 20	NA	42,717
All doctorate-granting	156,853	152,772
Women		
Top 20	NA	17,597
All doctorate-granting	57,876	71,285
	By field	
Engineering		
Top 20	12,409	14,091
All doctorate-granting	36,583	39,925
Physical sciences		
Top 20	5,843	6,103
All doctorate-granting	21,623	21,782
Environmental sciences		
Top 20	2,550	2,619
All doctorate-granting	9,356	9,824
Mathematics & computer sciences		
Top 20	3,754	3,754
All doctorate-granting	14,525	14,177
Life sciences		
Top 20	15,068	16,690
All doctorate-granting	61,993	66,582
Psychology		
Top 20	3,105	3,016
All doctorate-granting	21,431	20,695
Social sciences		
Top 20	12,335	14,041
All doctorate-granting	48,579	50,429
	By nationality	
U.S. students		
Top 20	NA	47,353
All doctorate-granting	179,689	178,663
Foreign students		
Top 20	NA	12,961
All doctorate-granting	34,401	44,751
	Postdoctoral Appointments	
Postdoctorals		
Top 20	NA	7,040
All doctorate-granting	19,753	18,600

[1] Ranked by total R&D expenditures in fiscal year 1980.

NA = Not available.

SOURCE: National Science Foundation, *Academic Science, 1972-1981* (NSF 81-326), and unpublished data.

See figure 5-7.

Science Indicators—1982

Appendix table 5-8. Proportion of institutions offering at least one course for non-specialists by field, course content, institutional type and control: 1980/81

Type of institution	Number of institutions	Physics	Chemistry	Biology	Mathematics	Computing[1]
		(Percent of institutions)				
		Field				
		Traditional subject matter courses				
Total	215	61	35	48	80	31
Research universities	47	81	26	45	79	32
Doctoral universities	32	69	31	53	78	38
Comprehensive universities/colleges	110	56	43	56	86	31
Liberal arts colleges	26	35	23	19	62	0
		Special subject matter courses				
Total	215	61	37	60	36	20
Research universities	47	75	40	68	40	26
Doctoral universities	32	69	47	75	31	25
Comprehensive universities/colleges	110	59	38	57	45	28
Liberal arts colleges	26	39	23	39	27	0

[1] Computer science departments or divisions have not been established in all post-secondary institutions. Of those surveyed, 39 research universities, 24 doctoral universities, 83 comprehensive universities/colleges, and 7 liberal arts colleges made such distinctions.

SOURCE: National Academy of Sciences, *Science for Non-Specialists: The College Years* (National Academy Press, 1983), pp. 44–45.

Science Indicators—1982

Appendix table 5-9. Expenditures for academic R&D by source: 1960-83

(Dollars in millions)

Year	Total	Federal Government	Industry	Universities & colleges	Other nonprofit institutions
			Current dollars		
1960	$ 646	$ 405	$ 40	$ 149	$ 52
1961	763	500	40	165	58
1962	904	613	40	185	66
1963	1,081	760	41	207	73
1964	1,275	917	40	235	83
1965	1,474	1,073	41	267	93
1966	1,715	1,261	42	304	108
1967	1,921	1,409	48	345	119
1968	2,149	1,573	55	390	131
1969	2,225	1,600	60	420	145
1970	2,335	1,648	61	461	165
1971	2,500	1,724	70	529	177
1972	2,630	1,795	74	574	187
1973	2,884	1,985	84	613	202
1974	3,023	2,032	96	677	218
1975	3,409	2,288	113	749	259
1976	3,727	2,512	123	808	284
1977	4,065	2,726	139	887	313
1978	4,621	3,057	170	1,035	359
1979	5,354	3,594	193	1,194	373
1980	6,050	4,093	235	1,314	408
1981	6,793	4,549	285	1,512	447
1982	7,010	4,695	320	1,540	455
1983	7,400	4,950	360	1,615	475
			Constant 1972 dollars[1]		
1960	$ 928	$ 582	$ 57	$214	$ 75
1961	1,085	711	57	235	82
1962	1,266	859	56	259	92
1963	1,489	1,047	57	285	101
1964	1,738	1,250	55	320	113
1965	1,965	1,431	55	356	124
1966	2,229	1,639	55	395	140
1967	2,417	1,774	60	434	150
1968	2,612	1,911	67	474	159
1969	2,582	1,857	70	487	168
1970	2,564	1,810	67	506	181
1971	2,613	1,803	73	553	185
1972	2,630	1,795	74	574	187
1973	2,763	1,900	80	587	193
1974	2,696	1,813	86	604	195
1975	2,766	1,856	92	608	210
1976	2,826	1,905	93	613	215
1977	2,888	1,937	99	630	222
1978	3,073	2,034	113	688	239
1979	3,276	2,199	118	730	228
1980	3,402	2,302	132	739	229
1981	3,480	2,329	146	774	229
1982	3,354	2,246	153	737	218
1983	3,371	2,256	164	736	216

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars. See appendix table 2-1 for deflators.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319) and preliminary data.

See figure 5-8.

Appendix table 5-10. R&D expenditures at doctorate-granting institutions, by source of funds, character of work, and science/engineering field: 1972-81

(Dollars in thousands)

Source, character, and field	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Total	$2,568,573	$2,809,160	$2,953,658	$3,338,409	$3,655,229	$3,985,994	$4,536,874	$5,264,748	$5,948,099	$6,681,762
					By source of funds					
Federal Government	$1,754,798	$1,938,225	$1,990,167	$2,241,149	$2,465,134	$2,677,112	$3,003,354	$3,533,226	$4,026,521	$4,476,150
State and local governments	261,026	282,281	294,547	325,209	355,769	364,943	405,708	460,497	482,653	528,483
Industry	73,006	81,783	93,781	110,098	120,076	135,012	165,494	189,292	231,192	278,985
Institutional funds	297,906	310,595	362,517	409,468	436,225	502,264	610,052	712,862	806,839	959,412
All other sources	181,837	196,276	212,646	252,485	278,025	306,663	352,266	368,871	400,894	438,732
					By character of work					
Basic research	$1,987,822	$2,021,690	$2,120,593	$2,370,779	$2,506,660	$2,757,227	([1])	$3,556,759	$3,958,617	$4,492,205
Applied research and development	580,751	787,470	833,065	967,630	1,148,569	1,228,767	([1])	1,707,989	1,989,482	2,189,557
					By field					
Engineering	$ 335,111	$ 328,206	$ 343,969	$ 377,107	$ 425,182	$ 490,931	$ 591,962	$ 760,616	$ 854,988	$ 949,448
Aeronautical and astronautical	NA	NA	NA	NA	NA	NA	NA	NA	46,544	45,415
Chemical	NA	NA	NA	NA	NA	NA	NA	NA	64,534	79,904
Civil	NA	NA	NA	NA	NA	NA	NA	NA	86,944	105,479
Electrical	NA	NA	NA	NA	NA	NA	NA	NA	182,973	190,773
Mechanical	NA	NA	NA	NA	NA	NA	NA	NA	144,230	145,917
Other engineering	NA	NA	NA	NA	NA	NA	NA	NA	329,763	381,960
Physical sciences	314,656	315,751	322,183	338,445	366,497	410,642	481,447	584,562	658,551	745,576
Astronomy	21,373	23,863	24,185	26,394	26,094	32,117	36,505	38,570	58,082	66,545
Chemistry	103,794	108,060	110,589	114,939	133,613	152,454	175,438	198,665	234,113	272,656
Physics	154,640	162,189	165,323	169,310	179,013	197,861	230,678	295,452	315,849	350,514
Other physical sciences	34,849	21,649	22,086	27,802	27,777	28,210	38,826	51,875	50,507	55,861
Environmental sciences	183,943	203,016	227,989	246,766	277,844	307,392	365,494	441,387	493,207	531,285
Mathematical & computer sciences	67,500	70,616	74,865	82,316	84,661	104,046	121,675	171,992	187,204	216,092
Mathematics	NA	35,587	36,486	37,916	41,330	51,050	57,342	77,049	76,477	85,730
Computer sciences	NA	35,029	38,379	44,490	43,331	52,996	64,333	94,943	110,727	130,362
Life sciences	1,308,592	1,506,802	1,606,025	1,881,524	2,081,677	2,234,749	2,513,599	2,800,155	3,180,525	3,626,579
Agricultural sciences	225,299	274,732	335,840	377,260	406,359	453,787	490,326	565,745	666,756	755,595
Biological sciences	435,296	547,007	500,394	619,719	700,143	758,929	843,995	952,603	1,014,030	1,167,014
Medical sciences	584,676	635,919	713,891	809,763	895,759	947,629	1,093,499	1,198,333	1,408,934	1,594,092
Other life sciences	63,321	49,144	55,900	74,782	79,416	74,404	85,779	83,474	90,805	109,878
Psychology	65,932	70,065	70,145	74,385	74,621	82,199	86,556	93,799	106,587	121,763
Social sciences	191,538	213,118	227,949	242,790	248,467	254,749	264,351	282,666	323,865	348,807
Other sciences	101,301	101,586	80,533	95,076	96,280	101,286	111,790	129,571	143,172	142,212

[1] Data were not collected in 1978.

NA = Not available.

SOURCE: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fiscal Year 1981* (NSF 83-308), p. 11, and earlier years.

See figures 5-9 and 5-12.

Appendix table 5-11. Relative distribution of R&D expenditures at universities and colleges by field[1]: 1972-81

(Percent)

Year	All S/E fields	Engi-neering	Physical sciences	Environmental sciences	Mathematics & computer sciences	Life sciences	Psy-chology	Social sciences	Other S/E fields
1972	100.0	13.0	12.3	7.2	2.6	51.0	2.6	7.5	4.0
1973	100.0	11.7	11.2	7.2	2.5	53.6	2.5	7.6	3.6
1974	100.0	11.7	10.9	7.7	2.5	54.4	2.4	7.7	2.7
1975	100.0	11.3	10.1	7.4	2.5	56.4	2.2	7.3	2.9
1976	100.0	11.6	10.0	7.6	2.3	57.0	2.0	6.8	2.6
1977	100.0	12.3	10.3	7.7	2.6	56.1	2.1	6.4	2.5
1978[2]	100.0	13.1	10.6	8.1	2.7	55.4	1.9	5.8	2.5
1979	100.0	14.5	11.1	8.4	3.3	53.2	1.8	5.4	2.5
1980	100.0	14.3	11.1	8.3	3.2	53.5	1.8	5.5	2.4
1981	100.0	14.7	11.2	8.0	3.2	54.3	1.8	5.2	2.1

[1] See appendix table 5-10 for a list of subfields.
[2] Data based on a survey of doctorate-granting institutions only.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fiscal Year 1981* (NSF 83-308), and earlier years.

See figure 5-10.

Science Indicators—1982

Appendix table 5-12. Relative concentration of Federal obligations for research[1] to universities and colleges by field: 1973-83

(Percent)

Year	All S/E fields	Life sciences	Psy-chology	Physical sciences	Environmental sciences	Mathematics & computer sciences	Engi-neering	Social sciences	Other sciences
1973	100.0	55.0	2.9	14.7	7.5	3.0	7.7	5.8	3.3
1974	100.0	59.4	3.1	13.1	7.0	2.9	7.6	4.9	2.1
1975	100.0	58.4	2.8	13.6	7.4	2.9	8.5	4.6	1.8
1976	100.0	57.9	2.7	12.9	7.8	2.7	8.0	5.5	2.5
1977	100.0	57.1	2.4	13.3	8.4	3.0	9.0	5.6	1.3
1978	100.0	57.9	2.4	13.2	8.2	2.9	8.7	5.3	1.4
1979	100.0	57.6	2.9	12.9	8.8	2.8	8.7	4.4	1.8
1980	100.0	57.3	2.6	13.3	8.6	2.7	9.4	4.0	2.2
1981	100.0	57.1	2.5	14.2	7.6	3.3	9.9	3.7	1.9
1982 (est.)	100.0	57.9	2.3	14.3	7.4	3.7	9.7	3.2	1.6
1983 (est.)	100.0	56.6	2.5	14.8	7.5	4.2	9.8	3.1	1.5

[1] Federal obligations by field are available for basic and applied research only, and do not include information about the distribution of development funds.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables, Fiscal Years 1967-83*, 1982.

Science Indicators—1982

Appendix table 5-13. Federal obligations for R&D to university and college performers for selected agencies: 1967-83

(Dollars in millions)

Year	All agencies	USDA	DoD	DHHS[1]	NSF	NASA	Other agencies
1967	$1,454.3	$ 64.2	$279.9	$ 619.8	$208.8	$124.1	$157.5
1968	1,487.4	61.1	244.4	677.2	221.0	130.6	153.1
1969	1,529.2	61.5	263.0	695.0	212.6	125.1	172.0
1970	1,475.6	64.8	216.3	646.6	228.0	131.2	188.7
1971	1,644.6	71.9	210.9	761.8	266.6	134.0	199.4
1972	1,903.6	87.5	216.8	915.9	362.5	119.0	201.9
1973	1,916.6	94.3	203.7	929.6	374.5	111.4	203.1
1974	2,214.0	94.8	197.4	1,207.7	389.4	98.9	225.8
1975	2,411.4	108.2	203.4	1,279.2	434.9	108.0	277.7
1976	2,551.8	119.7	240.5	1,365.0	436.6	118.9	271.1
1977	2,908.9	140.1	273.3	1,504.9	510.9	120.9	358.8
1978	3,377.6	186.4	383.2	1,702.3	537.2	130.2	438.3
1979	3,894.1	199.8	438.1	1,941.9	616.7	144.0	553.6
1980	4,276.9	216.4	495.3	2,075.6	684.9	171.2	633.5
1981	4,478.0	242.7	572.9	2,184.9	702.1	183.5	591.9
1982 (est.)	4,583.5	265.8	677.0	2,231.3	697.4	191.0	521.0
1983 (est.)	4,720.0	267.0	796.9	2,284.8	748.2	191.0	432.1

[1] Includes the education component of HEW through 1978, when the Department of Education was established and HEW became the Department of Health and Human Services.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables, Fiscal Years 1967-83*, 1982.

See figures 5-11.

Science Indicators—1982

Appendix table 5-14. R&D expenditures at university-administered federally funded research and development centers by character of work and S/E field: 1972-81

(Dollars in thousands)

Character and Field	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Total	$753,243	$816,923	$865,098	$986,736	$1,146,712	$1,383,814	$1,716,911	$1,934,797	$2,234,809	$2,476,273
					By character of work					
Basic research	$243,870	$296,492	$285,082	$308,981	$358,811	$402,168	([1])	$718,303	$774,080	$855,682
Applied research and development	509,373	520,431	580,016	677,755	787,901	981,646	([1])	1,216,494	1,460,729	1,620,591
					By field					
Engineering	$195,393	$251,539	$259,080	$275,682	$299,683	$380,420	$522,213	$561,083	$643,669	$655,010
Aeronautical and astronautical	NA	NA	NA	NA	NA	NA	NA	NA	24,778	60,339
Chemical	NA	NA	NA	NA	NA	NA	NA	NA	34,183	47,045
Civil	NA	NA	NA	NA	NA	NA	NA	NA	17,852	16,022
Electrical	NA	NA	NA	NA	NA	NA	NA	NA	203,657	168,163
Mechanical	NA	NA	NA	NA	NA	NA	NA	NA	104,309	185,401
Other engineering	NA	NA	NA	NA	NA	NA	NA	NA	222,890	178,040
Physical sciences	426,027	425,107	455,418	523,160	622,887	736,802	854,455	1,003,562	1,120,095	1,264,168
Astronomy	28,089	28,055	29,944	31,153	32,452	41,500	38,452	46,099	59,025	67,578
Chemistry	74,375	73,114	64,920	69,658	96,268	111,564	97,529	101,142	149,212	166,219
Physics	305,086	318,002	268,187	322,464	376,632	447,110	568,040	584,519	823,797	945,624
Other physical sciences	18,477	5,936	92,367	99,885	117,535	136,628	150,434	271,802	88,061	84,747
Environmental sciences	36,684	40,647	47,864	63,175	77,476	100,981	128,217	141,100	174,193	185,741
Mathematical & computer sciences	41,174	53,178	54,339	62,416	71,641	78,584	119,203	126,850	161,540	226,627
Mathematics	NA	14,744	16,002	17,715	22,063	15,358	8,100	6,614	128,054	38,561
Computer sciences	NA	38,434	38,337	44,701	49,578	63,226	111,103	120,236	33,486	188,006
Life sciences	35,854	33,964	34,367	42,284	50,198	57,949	58,439	73,441	75,499	84,156
Agricultural sciences	—	35	—	—	—	354	1,206	1,551	645	532
Biological sciences	28,810	24,344	26,211	31,661	38,253	43,569	48,154	62,659	56,106	65,694
Medical sciences	3,656	3,312	3,877	4,963	5,081	4,761	7,963	7,179	7,734	8,205
Other life sciences	3,388	6,273	4,279	5,660	6,864	9,265	1,116	2,052	11,014	9,725
Psychology	1,428	898	850	306	92	87	103	110	135	147
Social sciences	8,568	169	330	795	1,288	3,301	5,119	5,861	17,449	20,984
Other sciences	8,115	11,421	12,850	18,918	23,447	25,690	29,162	22,790	42,229	39,440

[1] Data were not collected in 1978.

NA = Not available

SOURCE: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fall 1981* (NSF 83-308), p. 129, and earlier years.

See figure 5-12.

Appendix table 5-15. Federal obligations to university-affiliated FFRDC's[1] by location and sponsoring agencies, for R&D and all activities: 1981

(Dollars in thousands)

Location	Name & supporting agencies	Total obligations	R&D obligations
Arizona	Kitt Peak National Observatory	$ 10,689	$ 10,689
	NSF	10,689	10,689
California	Jet Propulsion Laboratory	318,943	310,743
	HHS	103	103
	NASA	318,820	310,620
	NSF	20	20
	Lawrence Berkeley Laboratory	121,638	100,480
	DOE	112,430	92,124
	HHS	8,594	8,315
	NSF	614	41
	Lawrence Livermore Laboratory	445,942	343,375
	DOE	444,744	342,196
	HHS	1,198	1,179
	Stanford Linear Accelerator Center	66,497	55,620
	DOE	66,497	55,620
Colorado	National Center for Atmospheric Research	34,421	34,421
	NSF	34,421	34,421
Illinois	Argonne National Laboratory	223,021	205,213
	DOE	222,480	204,672
	HHS	541	541
	Fermi National Accelerator Laboratory	120,295	79,195
	DOE	120,295	79,195
Iowa	Ames Laboratory	16,744	16,744
	DOE	16,744	16,744
Massachusetts	Lincoln Laboratory	141,567	141,567
	DOD	137,767	137,767
	DOT	3,800	3,800
New Jersey	Plasma Physics Laboratory	105,627	66,196
	DOE	105,627	66,196
New Mexico	Los Alamos Scientific Laboratory	390,261	352,057
	DOE	388,797	350,593
	HHS	1,179	1,179
	INT	285	285
	Sacramento Peak Observatory	2,489	2,489
	NSF	2,489	2,489
New York	Brookhaven National Laboratory	172,573	120,768
	USDA	82	82
	DOE	168,992	117,298
	HHS	3,218	3,107
	NSF	281	281
Tennessee	Oak Ridge Institute for Nuclear Studies	12,542	11,552
	DOE	9,618	9,082
	HHS	1,266	1,242
	NSF	1,658	1,228
Virginia	Center for Naval Analysis	13,462	13,462
	DOD	13,431	13,431
	LABOR	31	31
West Virginia	National Radio Astronomy Observatory	13,002	13,002
	NSF	13,002	13,002
Puerto Rico	National Astronomical and Ionospheric Center	5,236	5,236
	NSF	5,236	5,236
Chile	Cerro Tolo Interamerican Observatory	4,830	4,830
	NSF	4,830	4,830

[1] Federally funded research and development centers.

SOURCE: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal year 1981* (NSF 83-315).

Science Indicators—1982

Appendix table 5-16. Doctoral scientists and engineers by type of employer and primary work activity: 1981

Type of employer	All activities	Research & development: Basic research	Research & development: Applied research	Research & development: Devel-opment	Management & ad-ministration: Of R&D	Management & ad-ministration: Other than R&D	Teaching	Consulting	Sales & professional services	Other[1] activities
Total	343,500	55,300	46,500	18,400	32,600	27,700	105,000	12,000	25,700	20,400
Business and industry	99,000	6,300	21,800	15,400	18,500	6,100	500	9,600	12,000	8,700
Educational institutions	186,800	37,900	13,700	1,000	4,400	14,500	103,900	1,000	4,900	5,500
Federal Government	25,100	6,100	6,800	800	5,800	1,900	100	400	800	2,400
Other employers[2]	32,600	4,900	4,100	1,100	3,900	5,200	500	1,100	8,000	3,800

[1] Includes 4,000 individuals who did not report primary work activity.
[2] Includes nonprofit organizations; hospitals/clinics; military/commissioned corps; State, local, and other government; other employers; and 600 individuals who did not report type of employer.

NOTE: Detail may not add to totals because of rounding. Statistics based on these rounded numbers may be slightly different from those presented in the text.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981* (NSF 82-332), p. 41.

Science Indicators—1982

Appendix table 5-17. Doctoral scientists and engineers employed in educational institutions by field and primary work activity: 1981

Field	Total	Research and development: Basic research	Research and development: Applied research	Research and development: Devel-opment	Management & ad-ministration: Of R&D	Management & ad-ministration: Other than R&D	Teaching	Consulting	Sales & professional services	Other[1] activities
Total	186,800	37,900	13,700	1,000	4,400	14,500	103,900	1,000	4,900	5,500
Physical scientists	28,300	7,800	1,700	300	800	1,500	15,500	100	100	600
Mathematical scientists	12,700	1,600	300	([2])	([2])	900	9,500	([2])	([2])	200
Computer specialists	3,000	400	200	300	100	400	1,500	100	100	([2])
Environmental scientists[3]	6,800	1,700	600	100	400	200	3,600	([2])	100	100
Engineers	18,100	1,600	2,300	200	1,000	2,000	10,500	200	200	100
Life scientists	56,800	20,200	6,100	200	1,200	3,500	21,800	200	1,700	2,000
Psychologists	21,800	2,100	1,200	([2])	300	2,400	12,400	300	2,500	700
Social scientists	39,300	2,400	1,300	([2])	600	3,700	29,200	100	200	1,700

[1] Includes individuals who did not report primary work activity.
[2] Less than 50.
[3] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding. Statistics based on these rounded numbers may be slightly different from those presented in the text.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981* (NSF 82-332), pp. 41–46.

See figure 5-13.

Science Indicators—1982

Appendix table 5-18. Academic[1] doctoral scientists and engineers engaged primarily or secondarily in R&D and consulting by field: 1981

Field	Total employed	R&D[2]			Consulting		
		Total	Primary	Secondary	Total	Primary	Secondary
All S/E fields	184,000	115,300	56,900	58,400	8,400	800	7,500
Physical scientists	28,100	19,300	10,600	8,700	600	100	600
Mathematical scientists	12,600	7,100	2,100	5,000	600	([3])	600
Computer specialists	3,000	2,000	900	1,100	400	100	300
Environmental scientists[4]	6,700	5,100	2,800	2,300	300	([3])	300
Engineers	18,100	11,800	5,100	6,700	1,600	200	1,400
Life scientists	56,700	42,500	27,600	14,900	1,400	200	1,200
Psychologists	20,200	9,600	3,500	6,100	1,600	200	1,400
Social scientists	38,800	18,000	4,400	13,600	2,000	100	1,800

[1] Excludes individuals employed by elementary/secondary school systems.
[2] Includes management of R&D.
[3] Less than 50.
[4] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding. Statistics based on these rounded numbers may be slightly different from those presented in the text.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1981.* (NSF 82-332), pp. 41–46, and unpublished data.

Science Indicators—1982

Appendix table 5-19. Full-time science and engineering graduate students in doctorate-granting institutions by source of support: 1974-81

Source of major support	1974	1975	1976	1977	1979	1980	1981	Average annual percent charge (1974-81)
Total	195,455	210,321	214,090	217,454	223,417	230,692	234,529	2.6
Federal agency total	47,989	48,249	48,593	50,377	52,874	52,852	50,844	.8
NIH	11,919	12,214	11,360	10,928	11,663	11,609	11,175	– .9
NSF	8,818	8,796	8,962	9,023	9,275	9,245	9,056	.4
DoD	5,547	5,084	4,798	4,993	4,998	5,239	5,608	.2
Other agencies	21,705	22,155	23,473	25,433	26,938	26,759	25,005	2.0
Institutional	75,223	77,083	79,217	80,404	82,829	86,722	90,441	2.7
Other sources	16,376	16,852	17,679	18,228	20,040	21,093	22,276	4.5
Other U.S.	11,847	11,440	11,372	11,322	12,494	13,103	13,745	2.1
Foreign	4,529	5,412	6,307	6,906	7,546	7,990	8,531	9.5
Self-support	55,867	68,123	68,593	68,436	67,684	69,934	70,968	3.5

SOURCE: National Science Foundation, *Academic Science/Engineering, Graduate Enrollment and Support, Fall 1981* (NSF 83-305), p. 97.

Science Indicators—1982

Appendix table 5-20. Age and use of scientific equipment in academic laboratories by investigator discipline: 1981

	Total	Investigator discipline: Cell biology	Organic chemistry	Solid state physics	Electrical engineering	Medical biology
No. of respondents	258	62	81	60	40	15
	Percent of instruments in laboratories					
5 yrs. old or less	49	43	49	47	59	55
6-10 yrs. old	26	29	25	24	19	38
11-15 yrs. old	16	16	15	18	18	6
Over 15 yrs. old	9	12	11	11	4	1
	Mean number of users[1]					
Inside lab	6.7	6.6	7.9	5.2	6.8	6.7
Outside lab	4.5	5.2	5.5	3.2	3.7	4.2
Percent of investigators listing 0-19% "downtime"[2]	95	98	90	95	100	100

[1] Estimates are based on the mean number of users of the single item in an investigator's laboratory with the largest number of users. "Inside lab" users are those in the investigator's research group.
[2] Percent of investigators listing 0-19 percent "downtime" due to mechanical or electronic problems.

SOURCE: Westat, Inc., *Indicators of Scientific Research Instrumentation in Academic Institutions: A Feasibility Study* (Rockville, Md.: 1982).

See table 5-5 in the text.

Appendix table 5-21. Distribution of research articles[1] written by U.S. scientists and engineers by field and research sector: 1973 and 1980

(Percent)

Field[2]	Year	Total	Universities and colleges	Federal Government	Industry[3]	Nonprofit institutions[3]	FFRDC's[4]	All others
All S/E fields	1973	100	65	11	11	7	3	3
	1980	100	68	10	9	8	3	2
	1973	100	64	12	4	15	1	5
Clinical medicine	1980	100	67	11	3	14	—	3
	1973	100	76	9	3	7	2	2
Biomedicine	1980	100	78	10	2	8	1	1
	1973	100	69	20	4	3	1	4
Biology	1980	100	75	16	3	4	—	2
	1973	100	68	8	18	2	3	1
Chemistry	1980	100	71	6	17	3	3	1
	1973	100	62	9	15	3	11	—
Physics	1980	100	61	6	17	4	11	—
	1973	100	67	16	6	3	6	2
Earth and space sciences	1980	100	68	15	6	4	6	1
	1973	100	39	9	41	3	5	2
Engineering and technology	1980	100	43	8	38	5	5	2
	1973	100	92	3	3	2	1	—
Mathematics	1980	100	91	2	3	3	1	—

[1] Based on the articles, notes and reviews by U.S. authors in over 2,100 of the influential journals on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2] See appendix table 1-13 for the subfields included in those fields.
[3] Including the federally funded research and development centers (FFRDC's) administered by these sectors.
[4] FFRDC's administered by universities.

NOTE: Detail may not add to the totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

Appendix table 5-22. Relative citation ratios[1] to 1973 and to 1978 U.S.-authored research articles,[2] by field and selected citing sector, from U.S.-authored research articles published from 1973 to 1980

Field[3]	1973	1978
	Colleges and universities	
All S/E fields	1.04	1.05
Clinical medicine	1.02	1.03
Biomedicine	1.00	1.01
Biology	1.10	1.06
Chemistry	1.10	1.13
Physics	1.00	.91
Earth and space sciences	1.04	1.05
Engineering and technology	1.24	1.21
Mathematics	.99	.99
	Industry	
All S/E fields	0.62	0.65
Clinical medicine	.75	.53
Biomedicine	.86	.71
Biology	.74	.87
Chemistry	.71	.70
Physics	1.22	1.40
Earth and space sciences	.70	.55
Engineering and technology	.82	.84
Mathematics	1.19	1.01
	Federal Government	
All S/E fields	1.08	1.09
Clinical medicine	1.20	1.18
Biomedicine	1.03	1.14
Biology	.79	.84
Chemistry	.80	.68
Physics	.72	.93
Earth and space sciences	.94	.83
Engineering and technology	.99	1.12
Mathematics	1.12	.99

[1] A citation ratio of 1.00 reflects no over- or under-citing of each sector's literature, whereas a higher ratio indicates a greater influence, impact, or utility than could be explained by the number of the sector's publications for that year.

[2] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[3] See appendix table 1-13 for the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 5-23. Percent change in the number of science and technology articles[1] by U.S. college and university authors by field: 1973-80

Field[2]	Number of articles 1973	1974	1975	1976	1977	1978	1979	1980	Percent change (1973 to 1980)
All S/E fields	67,573	65,197	63,511	66,019	65,024	66,863	67,170	66,987	−0.9
Clinical medicine	20,781	19,996	19,872	21,498	22,120	23,417	22,758	23,313	12.2
Biomedicine	12,322	11,960	12,238	12,569	12,628	13,019	13,711	13,686	11.1
Biology	7,734	7,498	7,099	7,627	7,169	7,138	7,661	7,193	−7.0
Chemistry	7,210	7,091	6,694	6,537	6,276	6,525	6,363	6,554	−9.1
Physics	7,259	7,226	6,912	6,941	6,772	6,774	6,844	6,964	−4.1
Earth and space sciences	3,769	3,611	3,209	3,490	3,347	3,499	3,526	3,262	−13.5
Engineering and technology	4,715	4,346	4,115	4,165	3,870	3,790	3,711	3,614	−23.4
Mathematics	3,784	3,466	3,373	3,194	2,842	2,702	2,599	2,400	−36.6

[1] Based on articles, notes and reviews from over 2,100 of the influential journals covered on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2] See appendix table 1-13 for the subfields included in these fields.

NOTE: Detail may not add to totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 5-17.

Science Indicators—1982

Appendix table 5-24. Concentration of scientific and technical articles by U.S. college and university authors by field and institutional rank[1]: 1975 and 1980

(Percent)

Field[2]	First 10 1975	First 10 1980	First 20 1975	First 20 1980	First 100 1975	First 100 1980
All S/E fields	21	21	35	35	83	85
Clinical medicine	25	26	43	41	92	93
Biomedicine	23	24	40	40	88	89
Biology	30	29	48	47	87	88
Chemistry	18	19	31	33	80	83
Physics	25	27	41	43	87	90
Earth and space sciences	30	32	49	52	90	90
Engineering and technology	25	26	39	42	86	89
Mathematics	20	23	34	37	84	85

[1] Ranked on the basis of number of articles published per institution.
[2] See appendix table 1-13 for the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 5-25. Distribution of scientific and technical articles[1] by U.S. college and university authors by field and level of research: 1973 and 1980

Field[2] and level of research	1973	1980	Percent change
Clinical medicine			
Basic research	8,448	9,930	17.5
Applied research	12,331	13,383	8.5
Biomedicine			
Basic research	11,871	13,250	11.6
Applied research	451	437	− 3.1
Biology			
Basic research	5,475	5,100	− 6.9
Applied research	2,259	2,094	− 7.3
Chemistry			
Basic research	7,021	6,382	− 9.1
Applied research	189	172	− 9.0
Physics			
Basic research	7,100	6,769	− 4.7
Applied research	158	196	24.1
Earth and space sciences			
Basic research	3,499	2,983	−14.8
Applied research	270	278	3.0
Engineering and technology			
Basic research	318	233	−26.7
Applied research	4,397	3,382	−23.1
Mathematics			
Basic research	3,407	2,133	−37.4
Applied research	377	267	−29.2

[1] Based on about 100,000 of the articles, notes, and reviews in over 2,100 of the influential journals of the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-13 for the subfields included in these fields.

NOTE: For this study, over 2,100 influential journals were assigned to two categories: the more basic and the more applied research. From field to field this assignment may represent somewhat different concepts of what the basic research literature is; however, the journals retained the same categorization throughout the years. See appendix table 5-26 for examples of the more basic and the more applied journals. For further information, see Francis Narin, *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity* (Cherry Hill, N.J.: Computer Horizons, Inc., 1976), pp. 198-199.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 5-18.

Science Indicators—1982

Appendix table 5-26. Examples of journals classified as "more basic" and "more applied" in appendix table 5-25

Field	The more basic	The more applied
Clinical medicine	Journal of Clinical Investigation Journal of Neurophysiology	Journal of the American Medical Association New England Journal of Medicine
Biomedicine	Advances in Human Genetics Journal of Biological Chemistry	Journal of Biosocial Science Journal of Medical Genetics
Biology	Journal of Economic Entomology Journal of Experimental Zoology	Journal of the Institute of Brewing Agronomy Journal
Chemistry	Journal of the American Chemical Society Analytical Chemistry	Journal of the American Leather Chemists Association Industrial Engineering Chemistry Process Design and Development
Physics	Reviews of Modern Physics Physical Review	Photogrammetric Engineering and Remote Sensing IEEE Transactions on Sonics and Ultrasonics
Earth and space sciences	Journal of Geophysical Research Journal of the Atmospheric Sciences	Solar Energy AAPG Bulletin (American Association of Petroleum Geologists)
Engineering and technology	IEEE Transactions on Nuclear Science Journal of Chemical and Engineering Data	Journal of the Iron and Steel Institute AICHE Journal (American Institute of Chemical Engineers)
Psychology	Psychological Bulletin Journal of Experimental Psychology	Journal of Personality and Social Psychology Perceptual and Motor Skills
Mathematics	Journal of the American Statistical Association Transactions of the American Mathematical Society	Quarterly Journal of Applied Mathematics SIAM Journal on Numerical Analysis

SOURCE: Computer Horizons, Inc., unpublished.

Science Indicators—1982

Appendix table 5-27. Index[1] of cooperative research based on scientific and technical articles[2] by field and selected research-performing sector: 1973 and 1980

Field[5]	Universities and colleges		FFRDC's[3]		Federal Government		Industry[4]		Nonprofit[4] institutions	
	1973	1980	1973	1980	1973	1980	1973	1980	1973	1980
Clinical medicine	54	61	51	57	61	74	38	50	65	71
Biomedicine	38	46	50	46	47	58	35	50	56	62
Biology	29	36	47	([6])	34	47	29	50	40	50
Chemistry	23	31	53	54	24	33	17	21	36	52
Physics	37	45	48	53	28	46	24	34	41	50
Earth and space sciences	37	47	47	63	42	52	43	55	47	52
Engineering and technology	32	39	28	33	29	42	19	29	25	39
Mathematics	23	32	([6])	([6])	24	48	36	47	49	54

[1] Consisting of the percentage of all articles which were written by scientists and engineers in a given organization with those from another organization: e.g., if S/E's from one university co-author an article with S/E's from another university or corporation, it is assumed here that there was some degree of cooperative research performed.

[2] Based on articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[3] Federally funded research and development centers administered by universities.

[4] Excluding the FFRDC's administered by this sector.

[5] See appendix table 1-13 for the subfields included in these fields.

[6] Because the total number of articles was less than 50, no index percentages are calculated.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1982

Appendix table 5-28. Publication patterns of dissertation research for selected fields.

Field	Number of respondents	Percent publishing	Average number of publications: Total	Average number of publications: Of those publishing	Percent cited by other publications
Total	593	50	0.9	1.9	47
Biochemistry	110	71	1.5	2.1	51
Zoology	118	62	1.4	2.2	41
Physics	88	60	.9	1.5	49
Electrical engineering	98	43	.7	1.6	30
Psychology	102	28	.4	1.5	72
Sociology	77	27	.6	2.1	58

NOTE: These data are based on publication counts through 1978 for a sample of 1,200 individuals who earned their S/E doctoral degrees in 1969/70.

SOURCE: Alan Porter, et al., *A Cross-disciplinary Assessment of the Role of the Doctoral Dissertation in Career Development* (Georgia Institute of Technology, 1981).

Science Indicators—1982

Appendix table 6-1. Composition of the various groups interviewed: 1981

	Percent			
	Leaders	Attentives	Potential attentives	Rest of public
By age:				
18–24		20	23	19
25–34	26	26	13	17
35–44		18	15	18
45–54	32	17	17	16
55–64	26	10	15	11
65 and over	14	8	16	19
By gender:				
Women	11	40	53	56
Men	89	60	47	44
By education:				
Less than high school	NA	8	19	24
High school graduate	NA	40	62	56
College[1]	NA	40	16	15
Graduate degree	NA	12	3	5
N =	287	637	617	1,941

NA = not available.

[1] Includes college graduates and those with at least some college training.

SOURCES: Leaders: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology,* (DeKalb, Ill.: Northern Illinois University, 1982), table 2; Attentives: Jon D. Miller, unpublished data.

Science Indicators—1982

Appendix table 6-2. Beneficial versus harmful consequences of scientific research: 1979

	Percent			
Response	Total public	Attentives	Potential attentives	Rest of public
Benefits have outweighed harms	70	88	74	63
About equal[1]	13	7	13	15
Harms have outweighed benefits	11	4	10	13
Don't know	6	—	4	9
N =	1,635	322	335	978

"Now, for a different type of question. People have frequently noted that scientific research has produced both beneficial and harmful consequences. Would you say that, on balance, the benefits of scientific research have outweighed the harmful results, or have the harmful results of scientific research been greater than its benefits?"

[1] Interviewers accepted "about equal" as a response, but did not suggest it.

SOURCE: Jon D. Miller, unpublished data.

Science Indicators—1982

Appendix table 6-3. Leaders' views of the international position of the U.S. in basic research and in applied research and technology: 1981

Percent saying U.S. is currently ahead of other countries	
• In basic scientific research	
Almost all areas	19
Most areas	59
Only a few areas	17
Don't know	4
• In applied research and technology	
Almost all areas	9
Most areas	57
Only a few areas	31
Don't know	3
	N = 287
Percent saying U.S. *should* be the leader in almost all areas	
Of basic scientific research	50
Of applied research and technology	38
	N = 287

Percent saying U.S. is ahead (should be ahead) in almost all areas of research, by sector and discipline

	Is ahead:		Should be ahead:		
	In basic scientific research	In applied research & technology	In basic scientific research	In applied research & technology	N
By sector:					
For-profit institutions	20	10	53	44	61
Universities	20	7	54	40	150
Non-profit institutions	16	10	37	30	67
By discipline:					
Biological sciences	18	9	64	43	44
Physical sciences	21	6	56	44	71
Social sciences	20	9	41	31	54
Engineering-professional	21	10	40	26	58
Other disciplines	13	13	52	46	54

"Now let me ask you to compare American science and technology to that of other countries. First, in terms of basic scientific research (applied science and technology), would you say that the United States is currently ahead of other countries in almost all areas . . . *in most areas* . . . *or in* only a few *areas of basic scientific research (applied science and technology)?*

As a matter of national policy, do you think the United States should *seek to be the leader in* almost all *areas of basic scientific research (applied science and technology), or should we focus our efforts on* only selected *areas of basic research (applied science and technology)?"*

SOURCE: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 47 and Jon D. Miller, unpublished data.

See table 6-4 in text.

Science Indicators—1982

Appendix table 6-4. Percentage of the public indicating "a great deal of confidence" in the people running nine institutions: 1973–82

Institution	1973	1974	1975	1976	1977	1978	1980	1982
Medicine	54	60	50	54	51	46	52	46
Scientific community	37	45	38	43	41	36	41	38
Education	37	49	31	37	41	28	30	33
Organized religion	35	44	24	30	40	31	35	32
Military	32	40	35	39	36	29	28	31
Major companies	29	31	19	22	27	22	27	23
Press	23	26	24	28	25	20	22	18
Television	19	23	18	19	17	14	16	14
Organized labor	15	18	10	12	15	11	15	12
N =	1,504	1,484	1,490	1,499	1,530	1,532	1,468	1,506

"I am going to name some institutions in this country. As far as the people running these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?"

SOURCE: James Allan Davis, Tom W. Smith, *General Social Surveys, 1972–1982,* (Chicago: National Opinion Research Center, 1982), pp. 111–114. These institutions are the nine which Alan Mazur discusses in "Commentary: Opinion Poll Measurement of American Confidence in Science," *Science, Technology & Human Values* (Summer 1981), pp. 16–19.

Science Indicators—1982

Appendix table 6-5. General public's views about the trustworthiness of information from institutions: 1982

Institution	Percent: Almost all of the time	Most of the time	Seldom	Never	Don't know or no answer
g. Medical community	18	61	16	3	2
h. Higher education	18	61	16	2	3
i. Organized religion	17	45	29	6	3
c. Newspapers and magazines	14	58	24	2	2
a. The military	14	45	30	7	4
b. Television	12	55	29	3	1
f. Scientific community	12	51	26	5	6
e. Environmentalist groups	11	49	30	6	4
j. Organized labor	8	38	41	8	5
d. Major companies	5	38	46	8	3
			N = 1,310		

"I am going to name some institutions in this country. Considering the information you get from these institutions, how often do you find them trustworthy?

NOTE: Items were asked in the indicated order, from a to j.

SOURCE: Research and Forecasts, Inc., survey performed for The Continental Group, Inc., Stamford, Conn., unpublished data.

Science Indicators—1982

Appendix table 6-6. Willingness to restrain scientific inquiry: 1979 and 1981

Respondents	Percent willing to prohibit scientific research concerning. . . New forms of life	Sex of child at conception	Intelligent life in outer space	Living to be 100+	Controlling weather	N
Attentives, 1979	51	NA	12	20	20	322
Attentives, 1981	50	50	24	20	20	637
Potential attentives, 1981	67	57	27	24	23	617
1981 attentives by age:						
18–24	50	48	21	29	32	116
25–34	47	48	19	17	13	208
35–44	51	46	27	17	23	104
45–54	51	62	23	13	19	98
55–64	50	55	25	18	11	62
65 and over	59	43	42	34	34	49
1981 attentives by gender:						
Women	60	55	29	23	23	253
Men	44	47	21	18	19	384
1981 attentives by education:						
Less than high school	55	35	29	24	19	48
High school	61	54	27	26	28	307
College[1]	41	49	20	14	13	203
Graduate degree	33	47	17	10	11	78

"Next, let me ask you about the types of studies that scientists ought to be able to conduct. Some people are worried that scientists are studying problems that should be left alone. Other people feel that it is a bad idea to limit the kinds of things that scientists can study.

I'm going to read you a short list of studies that have caused some debate. For each study, please tell me whether you think scientists should or should not be allowed to conduct that kind of research. If you don't care one way or the other, just give me that answer.

First, studies that might enable most people in society to live to be a hundred or more. Should scientists be allowed to conduct this type of study or not? . . . Studies that might lead to precise weather control and weather modification? . . . Studies that might allow scientists to create new forms of life? . . . Studies that might discover intelligent beings in outer space? . . . Studies that might allow parental selection of the sex of a child at the time of conception?"

[1] Includes college graduates and those with at least some college training.

NOTE: NA = not available

SOURCES: 1979: Jon D. Miller, unpublished tabulations; 1981: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 9.

See table 6-6 in text.

Science Indicators—1982

Appendix table 6-7. Index of willingness to restrain scientific inquiry: 1981
(Percent with each index score)

Respondents	Index score[1] 0	1 or 2	3 to 5	N
Attentives	24	49	27	637
Potential attentives	18	47	35	617
Attentives by age:				
18–24	25	42	34	116
25–34	30	48	22	208
35–44	26	50	24	104
45–54	20	53	27	98
55–64	14	64	22	62
65 and over	17	39	44	49
Attentives by gender:				
Women	21	45	34	253
Men	27	51	22	384
Attentives by education:				
Less than high school	21	53	25	48
High school diploma	17	47	36	307
College[2]	30	51	19	203
Graduate degree	41	46	13	78

[1] The index score is the number of topics on appendix table 6-6 that the respondent thought should not be studied.

[2] Includes college graduates and those with at least some college training.

SOURCE: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 10.

See table 6-6 in text.

Appendix table 6-8. General public's views on spending for selected programs: 1981

Program	Percent				
	Present spending amount is:				Loss will *not* be made up
	Too low	About right	Too high	Don't know	
h. Social services for the elderly	70	20	5	5	65
c. Education in general	53	32	10	5	54
g. Job training	50	31	11	9	54
b. Basic scientific research	39	37	15	9	48
d. College scholarships	38	37	15	10	54
e. Day care	37	33	14	16	56
f. School lunches	36	34	21	9	60
a. Support for the arts	17	43	22	18	40
			N = 1,500		

"Here is a list of some areas in American life. For each, please tell me if you think the total amount of spending on them—from all sources, government and non-governmental—at the present time is too high, too low, or about right. First, support for the arts. . . .

The government has been spending money for each of these areas, but there is now talk of cutbacks. For each one, please tell me if you think support from the private sector—such as corporations, private charities, churches, and individual citizens—will make up for the loss of government support, or not? First, support for the arts. . . ."

NOTE: Items were asked in the indicated order, from a to h.

SOURCE: American Enterprise Institute, release dated December 15, 1981.

Science Indicators—1982

Appendix table 6-9. Major problems for science and technology as identified by non-governmental S&T leaders: 1981

Problem	Percentages classifying the problem as major								
		By sector			By discipline				
	All S&T leaders	For profit	Uni-versity	Non-profit	Biological science	Physical science	Social science	Engineering & professional	Other fields
Funding for basic scientific research	66	51	75	58	75	62	76	62	61
Public understanding of science	48	33	51	52	57	44	44	52	39
Pre-collegiate science education	45	34	48	43	41	55	46	40	41
Scientific instrumentation for research	31	23	37	27	27	41	28	33	28
Training and research opportunities for young scientists	28	20	31	28	25	30	28	19	33
Incentives for industrial research and development	22	33	16	30	25	20	22	26	20
Applying new scientific knowledge toward end products and uses	19	16	19	24	14	15	28	17	22
N =	287	61	150	67	44	71	54	58	54

"Now, let me read you a list of some issues that other people have mentioned, and for each one—as I read it—I'd like for you to indicate if you think it is a major problem, a problem, but not major, or not really a problem."

SOURCE: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 10.

Science Indicators—1982

See table 6-8 in text.

Appendix table 6-10. Preferences for basic or applied emphasis in research funding: 1981

Respondents	Percent: Increase basic research	Maintain present balance	Increase applied research	Don't know	N
Potential attentives	27	46	25	2	617
Attentives	28	36	35	2	637
By age:					
18–24	26	30	44	1	116
25–34	25	35	39	—	208
35–44	30	30	37	2	104
45–54	33	34	32	1	98
55–64	34	41	20	5	62
65 and over	20	60	16	4	49
By gender:					
Women	31	33	34	3	253
Men	26	38	36	1	384
By education:					
Less than high school	32	43	24	2	48
High school graduate	25	38	36	2	307
College[1]	26	37	35	2	203
Graduate degree	40	21	38	1	78
Leaders	44	32	13	11	287
Biological scientists	64	23	7	7	44
Physical scientists	51	38	1	10	71
Social scientists	50	24	20	6	54
Engineers-professionals	29	35	16	21	58
Other disciplines	36	39	19	13	54

"Let me ask you to consider a situation in which the level of federal funds for scientific research and development would be essentially constant over a five to ten year period. In this situation would you favor reallocation of resources to increase basic scientific research, to increase applied research and development, or would you prefer the present balance?"

[1] Includes college graduates and those with at least some college training.

SOURCE: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill: Northern Illinois University, 1982), table 12; Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 16.

Science Indicators—1982

Appendix table 6-11. General public's views about the role government should play in various areas: 1981

Area	Percent			
	Major	Minor	None	Don't know
g. Seeing to it that all Americans get good health care	73	20	5	2
f. Protecting the environment	72	23	3	2
b. Encouraging economic development	70	23	4	3
h. Seeing to it that there are enough good jobs	63	25	9	2
d. Fostering basic research	56	33	6	5
c. Helping American business compete with foreign business	55	27	14	4
a. Increasing the number of Blacks and minorities in good jobs	33	34	31	3
e. Fostering the arts	20	46	27	7
		N = 1,500		

"I'm going to read you a list of areas in which government might play a role. For each, please tell me if you think the government should play a major role, a minor role, or no role at all. First, increasing the number of Blacks and minorities in good jobs. . . .

NOTE: Items were asked in the indicated order, from a to h.

SOURCE: American Enterprise Institute, release dated December 15, 1981.

Science Indicators—1982

Appendix table 6-12. Views about policies to promote technological innovation by American industry: 1981

Policy	Respondents	Percent					N
		Agree		Disagree		Don't know	
		Strongly	Other	Other	Strongly		
American industry should invest more heavily in scientific research and development.	Leaders	38	55	5	—	2	287
	Attentives	36	55	8	—	1	637
	Potential attentives	30	59	10	—	1	617
The Federal Government should provide larger tax incentives to increase industrial research and development.	Leaders	22	48	23	3	3	287
	Attentives	24	48	24	3	1	637
	Potential attentives	20	51	24	5	1	617
If patent laws in the U.S. were modified to extend the period of exclusive use, we would see a major increase in technological innovation.	Leaders	2	23	57	9	10	287
	Attentives	11	47	34	3	5	637
	Potential attentives	11	58	22	3	6	617

SOURCES: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 21, 22, 23; Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 24, 25, 26.

See table 6-10 in text.

Science Indicators—1982

Appendix table 6-13. General public's preferences for advances in technology: 1974, 1976, 1981

Field of technology	Percent: Would like continued advances 1974	1976	1981	Gone as far as should 1974	1976	1981	Gone too far now 1974	1976	1981	Don't know 1974	1976	1981
e. Medical transplants (heart, kidney, etc.)	88	89	90	5	5	5	2	2	2	4	4	3
f. Biological and medical engineering to improve or correct defects in human beings	NA	NA	82	NA	NA	9	NA	NA	4	NA	NA	5
k. Development of new food sources	83	76	76	7	11	12	3	5	4	7	8	5
g. Methods of local public transportation (buses, subways, etc.)	85	77	75	9	14	16	1	2	3	5	8	6
d. Nuclear power for peaceful purposes	70	70	59	16	13	19	5	8	12	9	9	10
a. Exploration of space	42	49	57	37	29	26	16	16	12	5	7	5
c. Cable TV technology, programming, and home information services	NA	NA	54	NA	NA	28	NA	NA	7	NA	NA	12
h. Synthetic fibers and materials (nylon, dacron, etc.)	67	65	54	19	21	29	3	4	6	11	10	12
b. Advanced weaponry (missiles, etc.)	40	45	50	35	27	25	19	18	16	7	10	8
j. Compact computers for home use	NA	NA	48	NA	NA	29	NA	NA	11	NA	NA	12
l. Automated and self-service shopping facilities (self-service food markets, gas stations, automated banking, etc.)	40	39	39	36	38	38	14	14	16	10	9	7
i. Synthetic foods (meat substitutes made from soy protein, chemicals, etc.)	34	36	35	26	26	27	23	27	26	23	10	11
(j.) Development of new living spaces (under sea, in space)	46	45	NA	22	24	NA	14	14	NA	18	16	NA
(f.) Speed of jet planes for long distance travel	31	29	NA	50	46	NA	10	16	NA	9	9	NA
(c.) Electronic surveillance devices (microphones, wire taps, etc.)	24	27	NA	34	31	NA	33	30	NA	9	11	NA

NA = not available.

NOTE: Items were asked in the indicated order, from a to l. Three substitutions were made in the 1981 survey.

SOURCE: The Roper Organization, *Roper Reports,* No. 8 (1981), p. 13.

See table 6-11 in text.

Appendix table 6-14. Expectation of future scientific achievements within 25 years: 1979 and 1981

		(b)	(a)	(e)	(c)	(d)	(f)	
		Percent who believe achievement is very likely						
		Cheap energy	Predict earthquakes	Desalinate salt water	Cure cancer	Communities in outer space	Control inflation & unemployment	N
Potential attentives	1979	59	54	45	48	17	NA	335
	1981	65	62	63	61	23	28	617
Attentives	1979	81	72	64	58	28	NA	322
	1981	74	63	62	59	21	19	637
1981 attentives by age:								
18–24		49	68	15	61	47	21	116
25–34		66	75	22	64	61	25	208
35–44		59	78	14	63	70	18	104
45–54		68	77	18	67	59	20	98
55–64		74	63	24	66	58	16	62
65 and over		63	88	29	54	59	22	49
1981 attentives by gender:								
Women		53	70	23	66	59	15	253
Men		69	77	17	61	59	25	384
1981 attentives by education:								
Less than high school		58	68	18	74	62	44	48
High school graduate		61	78	23	64	60	20	307
College[1]		64	71	15	64	58	17	203
Graduate degree		67	74	17	52	56	19	78

"Now, let me ask you to think about the long-term future. I am going to read you a list of possible scientific results and ask you how likely you think it is that each of these results will be achieved in the next 25 years or so. a.) A way to predict when and where earthquakes will occur. Do you think that it is very likely, possible but not too likely, or not likely at all that researchers will achieve this result within the next 25 years or so? b.) More efficient sources of cheap energy. c.) A cure for common forms of cancer. d.) A way to put communities in outer space. e.) A way to economically desalinate sea water for human consumption. f.) An economic theory to control inflation and reduce unemployment."

[1] Includes college graduates and those with at least some college training.

NOTE: Items were asked in the indicated order, from a to f.

SOURCE: Jon D.Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 7.

See table 6-12 in text.

Science Indicators—1982

Appendix table 6-15: Optimism that science and technology can solve the energy problem: 1981

Respondents	Percent: Strongly agree	Agree	Disagree	Strongly disagree	Don't know	N
Leaders	28	55	11	4	1	287
Attentives	32	55	11	2	1	637
Potential attentives	29	59	10	2	—	617

"We can depend on science and technology for a long-term solution to the energy problem."

SOURCES: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 33, and Jon D. Miller, unpublished data.

Science Indicators—1982

Appendix table 6-16. Views about recombinant DNA research: 1981 (Percent)

Benefits/risk balance of recombinant DNA research:

Respondents	Benefits outweigh risks	Benefits equal risks[1]	Risks outweigh benefits	Don't know	N
Leaders	76	4	7	13	287
Attentives	58	4	32	7	637
Potential attentives	47	7	35	11	617

Present level of government regulation of recombinant DNA or genetic engineering experiments is:

Respondents	Too high	About right	Too low	Don't know	N
All leaders	17	58	9	15	287
Biological scientists	23	61	7	9	44
Physical scientists	21	51	8	20	71
Engineers-professionals	21	64	7	9	58
Social scientists	11	63	13	13	54
Other scientists	13	54	11	22	54

"... some persons have argued that the creation of new life forms through recombinant DNA research constitutes a serious risk, while other persons have argued that recombinant DNA research may yield major benefits for society. In your own opinion, would you say that the risks of recombinant DNA research are greater than its benefits or that the benefits are greater than the risks?"

"Recombinant DNA or genetic engineering experiments. Is the present level of government regulation too high, too low, or about right?"

[1] Reported only when volunteered by respondents.

SOURCES: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 36, 37; Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (Dekalb, Ill.: Northern Illinois University, 1982), table 25.

Science Indicators—1982

Appendix table 6-17. Views about nuclear power: 1981 (Percent)

Benefit-risk assessment of nuclear power:

Respondents	Benefits outweigh risks	Benefits equal risks[1]	Risks outweigh benefits	Don't know	N
Leaders	60	4	30	6	287
Attentives	55	—	45	—	637
Potential attentives	51	—	47	2	617

Present level of government regulation of the construction of nuclear plants is:

	Too high	About right	Too low	Don't know	N
All leaders	25	40	33	2	287
Biological scientists	40	35	24	2	58
Physical scientists	31	42	21	6	71
Engineers-professionals	27	41	32	—	244
Social scientists	11	33	54	2	54
Other scientists	13	50	35	2	54

[1] Reported only when volunteered by respondents.

SOURCES: Jon D. Miller, *A National Survey of the Non-governmental Leadership of American Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), tables 34, 35; Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 24.

Science Indicators—1982

Appendix table 6-18. Perceived benefits/risk balance of nuclear power: 1981

	Percent						
	Benefits strongly outweigh risks	Benefits slightly outweigh risks	Benefits equal risks[1]	Risks slightly outweigh benefits	Risks strongly outweigh benefits	Don't know	N
Potential attentives	26	25	—	16	31	2	617
Attentives	35	20	—	16	29	—	637
By age:							
18–24	26	23	—	15	36	1	116
25–34	31	21	—	17	30	1	208
35–44	33	19	—	13	35	—	104
45–54	51	15	2	11	20	—	98
55–64	29	19	—	19	34	—	62
65 and over	53	19	—	17	11	—	49
By gender:							
Women	28	19	—	19	34	—	253
Men	40	20	—	13	26	1	384
By education:							
Less than high school	48	18	—	20	15	—	48
High school graduate	37	19	—	14	31	1	307
College[2]	33	22	—	12	32	—	203
Graduate degree	25	22	—	26	27	—	78

[1] Reported only when volunteered by respondents.
[2] Includes college graduates and those with at least some college training.

SOURCE: Jon D. Miller, *A National Survey of Public Attitudes Toward Science and Technology* (DeKalb, Ill.: Northern Illinois University, 1982), table 24.

Science Indicators—1982

Appendix table 6-19. Percent saying we are spending too little on solving certain problems: 1973–82

Problem	1973	1974	1975	1976	1977	1978	1980	1982
b. Improving and protecting the nation's health	61	67	62	60	56	55	55	56
e. Halting the rising crime rate	64	67	65	65	65	64	69	71
f. Dealing with drug addiction	65	60	55	58	55	55	59	57
c. Improving and protecting the environment	61	59	53	55	47	52	48	50
g. Improving the nation's education system	49	50	49	50	48	52	53	57
d. Solving the problems of the big cities	48	50	47	42	40	39	40	43
h. Improving the conditions of Blacks	32	31	27	27	25	24	24	28
i. The military, armaments and defense	11	17	17	24	24	27	56	29
k. Welfare	20	22	23	13	12	13	13	20
a. The space exploration program	7	8	7	9	10	12	18	12
j. Foreign aid	4	3	5	3	3	4	5	5
N =	1,504	1,484	1,490	1,499	1,530	1,532	1,468	1,506

"We are faced with many problems in this country, none of which can be solved easily or inexpensively. I'm going to name some of these problems, and for each one I'd like you to tell me whether you think we're spending too much money on it, too little money, or about the right amount. First ________ . . are we spending too much, too little, or about the right amount on ________?"

NOTE: Items were asked in the indicated order, from a to k.

SOURCE: James A. Davis and Tom W. Smith, *General Social Survey, 1972–1982.* (Chicago: National Opinion Research Center, University of Chicago, 1982), pp. 76–79.

Science Indicators—1982

Appendix table 6-20. General public's self-professed interest in and knowledge about issues in the news: 1981

Issue	Percent: Degree of interest: Very interested	Moderately interested	Not at all interested	Don't know	Percent: Level of knowledge: Very well informed	Moderately informed	Poorly informed	Don't know
e. Economic issues and business conditions	54	36	10	—	30	51	19	—
h. Energy policy	50	40	10	—	24	56	20	—
c. Local school issues	46	36	18	—	32	46	22	—
d. New scientific discoveries	38	45	16	—	13	50	37	—
a. International and foreign policy issues	36	47	17	—	18	55	27	—
f. Use of new inventions and technologies	34	51	15	—	11	49	39	—
b. Agricultural and farm issues	24	48	28	—	13	43	44	—
i. Space exploration	26	44	30	—	14	47	39	—
g. Women's rights issues	24	48	28	—	18	54	28	—
	N = 3,195							

"There are a lot of issues in the news and it is hard to keep up with every area. I am going to read you a short list of issues and for each one—as I read it—I would like you to tell me if you are very interested, moderately interested, or not at all interested in that particular issue."

"Now I'd like to go through this list with you again and for each issue I'd like for you to tell me if you are very well informed about that issue, moderately well informed, or poorly informed."

NOTE: Items were asked in the indicated order, from a to i.

SOURCE: Jon D. Miller, unpublished data.

Science Indicators—1982

Appendix table 6-21. Self-professed understanding of scientific terms: 1981

Term	Percent							
	Attentives (N = 637)				Potential attentives (N = 617)			
	Clear understanding	General sense	Little understanding	Don't know	Clear understanding	General sense	Little understanding	Don't know
Radiation	73	25	1	—	34	55	9	2
GNP	62	17	22	—	12	28	59	2
Scientific study	49	48	3	—	20	54	24	2
DNA	37	40	23	—	4	33	61	2

"When you read science related news stories, you encounter certain sets of words and terms. We are interested in how many people recognize certain types of scientific terms and I would like to ask you four brief questions in that regard. First, numerous articles speak of the results of a scientific study. When you read the term "scientific study" do you have a clear understanding of what it means, a general sense of what it means or little understanding of what it means?". . . .

SOURCE: Jon D. Miller, unpublished data.

Science Indicators—1982

Appendix II
Contributors and Reviewers

Contributors and Reviewers

The following individuals contributed to the report or reviewed its chapters and sections. Their participation is greatly appreciated.

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Subject Index

Subject Index

Q

R

T

U

V

W

X

Y

Z

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